The Gravitino in the corners of Moduli Space

String Phenomenology 2022, Liverpool

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Based on [arXiV: 2104.10181]

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Overview

- ★ Swampland Program: Can every apparently consistent EFT be embedded in a consistent theory of QG?

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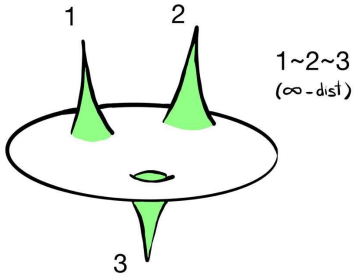
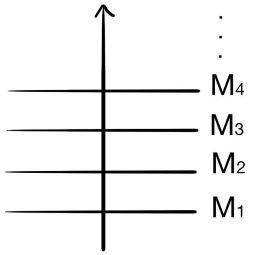


Universal Behaviour ➡ Too general!

INFINITE TOWER OF STATES



Special Direction: Gravitino mass, $m_{3/2}$ going to 0!!

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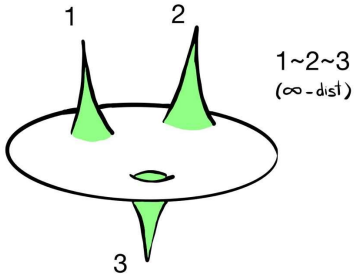

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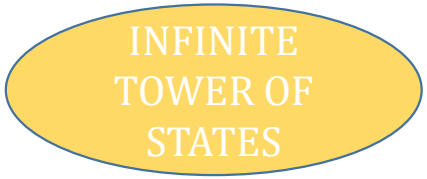
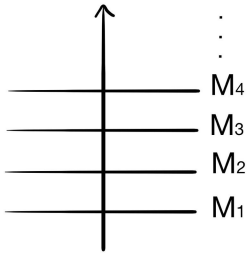
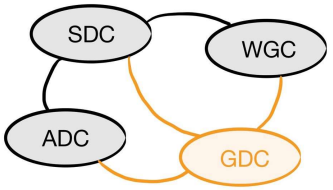




Special Direction: Gravitino mass, $m_{3/2}$ going to 0!!

★ GDC: Theory of QG, $m_{3/2} \neq 0,\ m_{3/2} \to 0$ ➡ Tower of massless states



$$m_{\rm tow} \sim m_{3/2}^{\delta}$$
$$\delta > 0$$

$(M_{\rm P} = 1)$

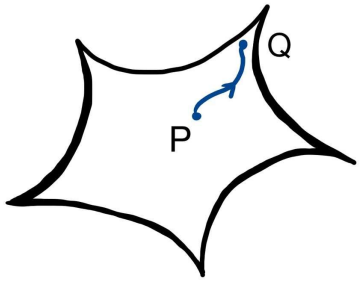
See also [Cribiori, Lust, Scalisi, '21] for related ideas

Outline

I.	INTRODUCTION	Recap of main Swampland Conjectures
II.	THE GDC	Stating the Conjecture. Relation to SDC, ADC &WGC
III.	EVIDENCE FOR THE GDC	Type II(A) examples. Generalities. F-theory 'uplift'.
IV.	PHENOMENOLOGY	Main Implications for Part. Physics & Cosmology
V.	SUMMARY	Quick Recap of main Results

Introduction: SDC

★ *Swampland Distance Conjecture:*



$$\mathcal{L}_{\text{kin}} \sim \tfrac{1}{2} g_{ij} \partial_\mu \phi^i \, \partial^\mu \phi^j$$

Starting from a point P in moduli space, and moving to a point Q an infinite distance away, there appears a tower of states which becomes exponentially massless according to

$$\frac{m(Q)}{M_p} \sim \frac{m(P)}{M_p} \, e^{-\alpha d(P,Q)}$$

[Ooguri, Vafa, '06]

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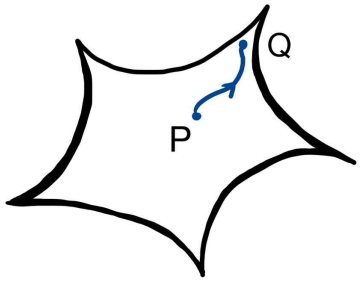

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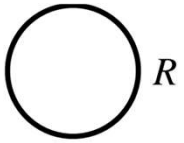
★ SDC ➡ 'Universal Behaviour' near ∞ - distance points

$$M_{\text{tower}} \sim e^{-\alpha d} \xrightarrow{d\to\infty} 0$$



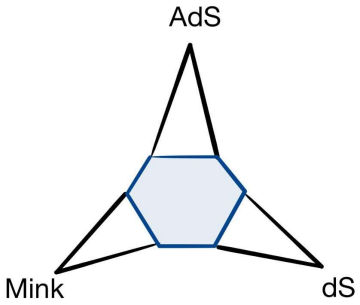
$R \to \infty$ Kaluza-Klein tower

$R \to 0$ Winding tower

e.g. KK tower $\quad m_n^2 = n^2/R^2, \;\; n \in \mathbb{Z}$

$\mathcal{L}_{\text{kin}} \sim \frac{(\partial R)^2}{R^2} \Rightarrow d = \log R + c \quad$ with $m_n \sim e^{-d}$

Introduction: ADC



Anti de-Sitter Distance Conjecture: In a theory of quantum gravity with cosmological constant Λ there exist a tower of states that becomes light in the limit $\Lambda \to 0$, whose masses behave as

$$\frac{m}{M_p} \sim \left| \frac{\Lambda}{M_p^2} \right|^{\gamma}$$

[Lust, Palti, Vafa, '19]

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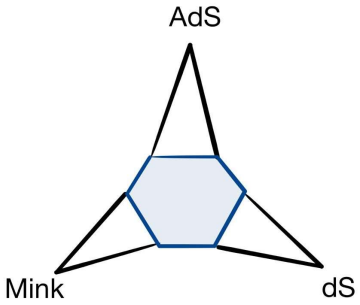

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★ Strong version:

- $\gamma = 1/2$ SUSY vacua
- $\gamma \geq 1/2$ non SUSY AdS
- $\gamma \leq 1/2$ dS vacua

Weak version supported by all known examples. Strong version in tension with e.g. DGKT

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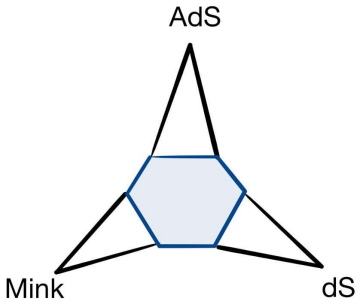

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★ Motivated from a generalization of the SDC

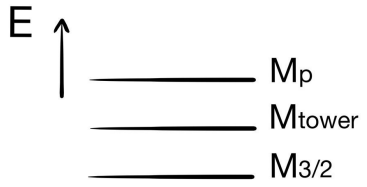
if $m = M_{KK} \Rightarrow R_{\text{int}} \sim R_{\text{AdS}}$ with $-\Lambda \sim \frac{1}{(R_{\text{AdS}})^2}$ e.g. Type IIB in $AdS_5 \times S^5$

The Gravitino Distance Conjecture

In a supersymmetric theory with a non-vanishing gravitino mass $m_{3/2}$, in the limit $m_{3/2} \to 0$, a tower of states becomes light according to

$$\frac{m_{\text{tower}}}{M_p} \sim \left(\frac{m_{3/2}}{M_p}\right)^{\delta}, \qquad 0 < \delta \leq 1$$

[Focus on $\mathcal{N} = 1$ supersymmetric theories here]



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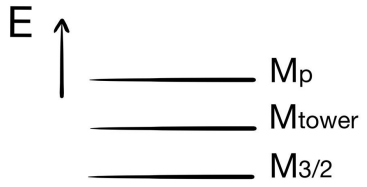

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★ Can approach $m_{3/2} \to 0$ in two qualitatively different ways

- $m_{3/2} = m_{3/2}(\phi^i)$ with ϕ^i unfixed — Minkowski no-scale
- $m_{3/2} = m_{3/2}(\alpha^j)$ with α^j fixed — AdS

$$\mathcal{M}_{sm} = \mathcal{M}_{discrete} \otimes \mathcal{M}_{continuous}$$

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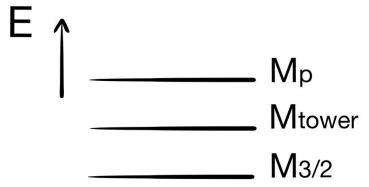

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★ Note that in $4d$, $N = 1$ supergravity

$$(M_{\rm P} = 1) \quad m_{3/2} = e^{K/2}\,|W|$$

K = Kähler potential

W = superpotential

Evidence for the GDC

- Evidence for the Gravitino Conjecture from relations to other Swampland Conjectures

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Magnetic WGC: $\Lambda_{UV} \lesssim eM_p \longrightarrow$ Tower of states

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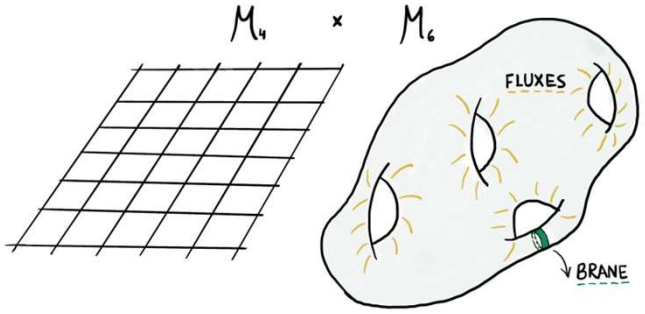
- ★ Type IIA Toroidal Orientifold with fluxes $(T^6/\mathbb{Z}_2 \times \mathbb{Z}_2')$
- ★ Moduli ➡ S, T, U
- ★ Fluxes: RR NSNS

$$F_0,\ F_2,\ F_4,\ F_6 \qquad H_3$$
$$(m,\ c,\ e,\ e_0) \qquad (h_0,\ h)$$



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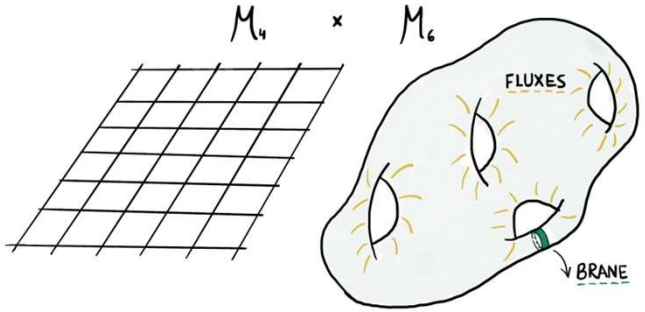

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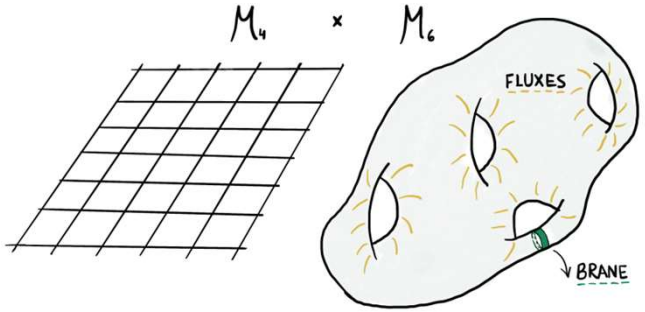

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- ★ No-scale Minkowski vacua (one linear combination of S, T fixed, U unfixed):

$$W = e_0 + 3ieT + 3cT^2 + imT^3 + ih_0S \qquad m_{KK} \simeq m_{3/2}^{\delta} \qquad 1 \geq \delta \geq \frac{11}{15}$$

- ★ No-scale Minkowski vacua on twisted tori (S, T fixed, U unfixed):

$$W = 3cT^2 + imT^3 + ih_0S - 3aST \qquad m_{KK} \simeq m_{3/2}^{2/3}$$

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e.g. *hm*, *ac*,…

Complex structure

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← Complex structure

II Can constrain further the range for δ

Reliable EFT + Perturbative Regime ➡ $\frac{1}{3} \leq \delta \leq 1$

$m_{3/2} \lesssim M_{KK} \lesssim M_s$ $\qquad$ $e^{\phi}, e^{\phi_4} = \frac{e^{\phi}}{\sqrt{\mathcal{V}}} \lesssim 1$

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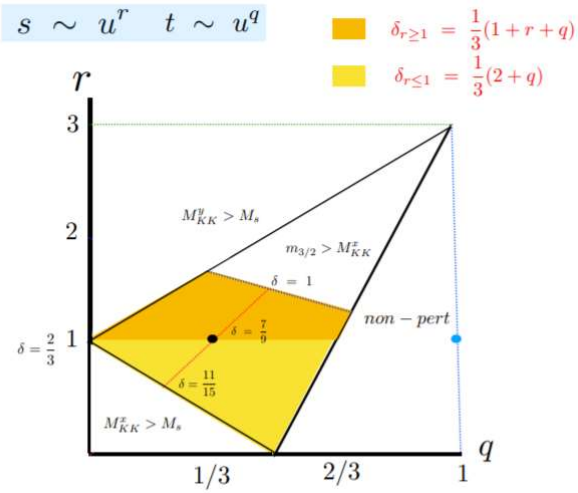
→ $\boxed{\frac{1}{3} \leq \delta \leq 1}$

III Also strings & membranes get light as $m_{3/2} \to 0$

Scales	M_s $(su^3)^{-1/4}$	M_{KK} $(su^3t^2)^{-1/4}$	M_{KK}^x $(stu)^{-1/2}$	M_{KK}^y $(ut^{1/2})^{-1}$
T_{strings}	D4(B^0) s^{-1}	D4(B^I) u^{-1}	NS5^a t^{-1}	
T_{mem}	Dp $(su^3t^{(5-p)})^{-1/2}$	NS5^0 $(s^{-1}u^3t^3)^{-1/2}$	NS5^I $(st^3u)^{-1/2}$	

Table 1: Masses and tensions of KK states and branes in an isotropic $\mathbb{Z}_2 \times \mathbb{Z}_2'$ type IIA orbifold in Planck units.



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- We will recover previous results in AdS & Mink

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★ General Results

I Two scalar fields: s,t

Scalar potential

$$V_{\rm IIA} = \frac{1}{s^3}\left(\frac{V_{F_0}t^3}{s} + \frac{V_{F_2}t}{s} + \frac{V_{F_4}}{st} + \frac{V_{F_6}}{st^3} + \frac{V_{h_0}s}{t^3} + \frac{V_a s}{t} + V_{g_1}st + V_{g_2}st^3 - V_{\rm loc}\right)$$

[Grimm, Li, Valenzuela,'20]

Vacua at parametric control ➡ $s \sim \rho^r, t \sim \rho^q$

AdS (non)SUSY & Mink

$$\delta = 7/9$$

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$$V_{\rm IIA} = \frac{1}{s^3}\left(\frac{V_{F_0}t^3}{s} + \frac{V_{F_2}t}{s} + \frac{V_{F_4}}{st} + \frac{V_{F_6}}{st^3} + \frac{V_{h_0}s}{t^3} + \frac{V_a s}{t} + V_{g_1}st + V_{g_2}st^3 - V_{\rm loc}\right)$$

[Grimm, Li, Valenzuela,'20]

- Vacua at parametric control ➡ $s \sim \rho^r, t \sim \rho^q$

AdS (non)SUSY & Mink

$$\delta = 7/9$$

II Tensionless membranes and strings

- Using MHS

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Evidence for the GDC

★ General Results

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III GDC vs SDC

CLAIM!!

Flat directions ➡ $m_{3/2} \to 0$ ➡ ∞ - dist.

Toroidal models

$$\frac{1}{\sqrt{6}} \leq \alpha \leq \sqrt{\frac{3}{2}}$$

Generalization (MHS)

$$\frac{3}{\sqrt{2}} \geq \alpha \geq \frac{1}{\sqrt{6}}$$

Pheno

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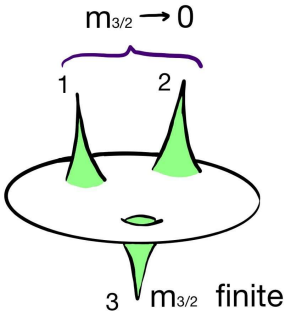
- In Cosmology, EFT valid if $M_{KK} \gtrsim H$ ➡ $H \lesssim m_{3/2}^{\delta} {M_{\rm P}}^{1-\delta}$

Summary

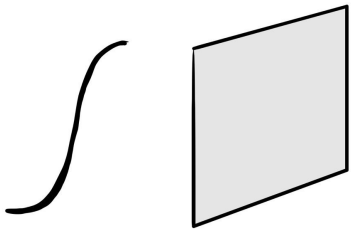
★ $m_{3/2} \to 0$ selects particular field directions



$$m_{\rm tow} \sim m_{3/2}^{\delta}$$
$$\delta > 0$$

Typically KK tower

Also subleading towers from tensionless strings & membranes



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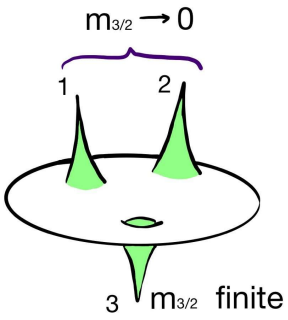

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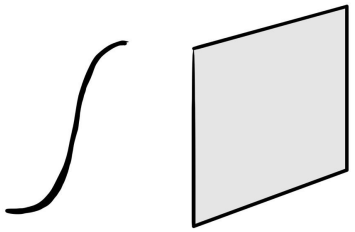

★ Direct relation with WGC

3-form gauge couplings $\xrightarrow{m_{3/2}\to 0}$ 0 ➡ Singular Limit

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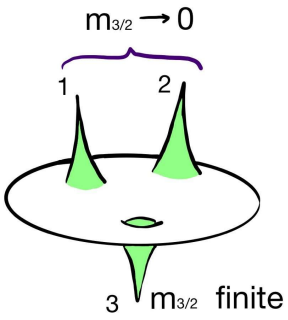

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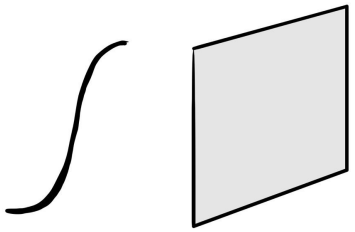

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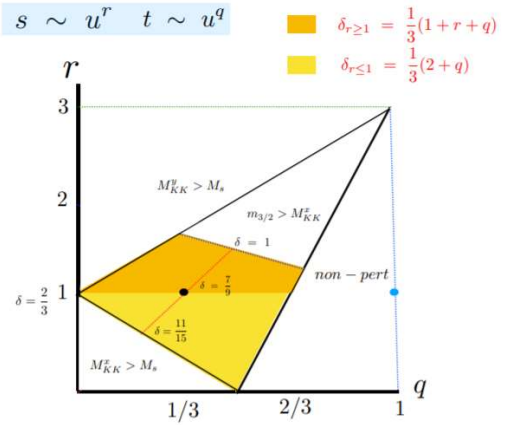

★ Evidence for GDC in Type IIA CY_3 Orientifolds

And also in F-theory CY_4 flux compactifications

Summary

- Pheno implications

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  - Particle Physics: two scenarios
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★ Future Work

Examples in type IIA classical vacua ➡ Quantum vacua??

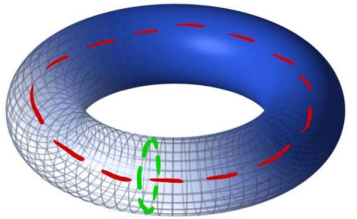
GDC consistent with full moduli stabilization, e.g. LVS, KKLT ??

Study more examples (e.g. [Coudarchet, Dudas, Partouche, '21])

Thank you for your attention!

Contact: alberto.castellano@csic.es

Back-up: Toroidal Orientifold



- ★ Type IIA CY_3 Orientifolds ➡ $N = 1, D = 4$ Supergravity
  - Focus on toroidal example: $T^6/\mathbb{Z}_2 \times \mathbb{Z}_2'$
- ★ Three maximally symmetric type of vacua
  - AdS examples $(\Lambda < 0)$
    - DGKT-CFI (no metric fluxes) ➡ SUSY and non-SUSY sols
    - AdS with metric fluxes ➡ SUSY and non-SUSY sols
  - Minkowski examples $(\Lambda = 0)$
    - No-scale models ➡ Broken SUSY
    - Two cases
      - $m_{3/2}$ depends on single unfixed modulus
      - More than one no-scale direction
  - dS examples $(\Lambda > 0)$
    - Runaway solutions
    - $m_{3/2}$ directly related to tension of membranes

$\delta = 7/9$

$\delta = 1$

$\delta = 2/3$

Range for δ