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The Gravitino and the Extra Dimensions

WIP with **M. Scalisi** and **D. Lüst**

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Corfu2025: Workshop on Quantum Gravity and Strings

September 11, 2025

In this talk:

1. **Introduction**
   - **Main goal and motivations**
   - **Connecting $m_{3/2}$ with Extra Dimensions**
   - **Setup**
2. Results

Conclusions

Introduction

Main goal:

Quantify the connection between the supersymmetry (SUSY) breaking scale M_{SUSY} and the features of the extra dimensions (**EDs**).

Motivations:

- Both SUSY and extra dimensions EDs are possible predictions of superstring theory. The absence of their experimental detection leads to bounds.

For the scale of SUSY breaking M_{SUSY}:

$$M_{SUSY} > \mathcal{O}(10)\, TeV$$

Based on LHC results showing no evidence of superpartners.
[Particle Data Group '22]

For the scale l at which EDs are compactified:

$$l < 38.6\, \mu m$$

Derived from tests of Newton's law and no deviations detected.
[Lee, Adelberger, Cook, Fleisher, Heckel '20]

Introduction

Main goal:

Quantify the connection between the supersymmetry (SUSY) breaking scale M_{SUSY} and the features of the extra dimensions (**EDs**).

Motivations:

- Historically, to solve the *electroweak hierarchy problem* it was considered to restore SUSY at low scales **or** to lower the higher dimensional Planck mass, i.e. :

$M_{SUSY} \sim TeV$ scale

[Weinberg's textbook]

or

two ~millimeter-sized EDs in the **ADD** model.

[Arkani-Hamed, Dimopoulos, Dvali '98]

- Recently, the *Dark Dimension scenario* (**DD**) linked ***one ~micron-sized ED*** to the *small cosmological constant* by extending the ***Anti de-Sitter Distance Conjecture*** *(**ADC**)* to the *de-Sitter case* within the *Swampland Program.* In this scenario, the ***Gravitino Conjecture (GC)*** was also invoked to *connect* a TeV-scale SUSY breaking to the cosmological constant.

[Vafa '05]; [Lüst, Palti, Vafa '19]; [Cribiori, Lüst, Scalisi '21]; [Castellano, Font, Herraez, Ibañez '21]; [Montero, Vafa, Valenzuela '22]; [Anchordoqui, Antoniadis, Cribiori, Lüst, Scalisi '23]

Introduction - why gravitino?

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- The gravitino is a key-particle to explore Quantum Gravity and in a quasi-flat spacetime its mass $m_{3/2}$ is related to M_{SUSY} as:

$$M_{SUSY}^2 \sim m_{3/2} M_{pl} \,.$$

Gravitino Conjecture:

In Planck units, the limit of **small gravitino mass** $m_{3/2} \to 0$ always corresponds to the **massless limit of an infinite tower of states**, yielding the breakdown of the EFT.

[Cribiori, Lüst, Scalisi '21]
[Castellano, Font, Herraez, Ibañez '21]

- The **gravitino mass** $m_{3/2}$ is linked to the **KK scale** (in Planck units) as:

$$\boldsymbol{m_{KK} \sim (m_{3/2})^n}$$

n is an $\mathcal{O}(1)$ parameter.

Connecting $m_{3/2}$ with EDs

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- In DD scenario, assuming (dS)**ADC** and **GC** we have:

one ~micron-sized ED $\Longleftrightarrow$ **small cosmological constant** $\Longleftrightarrow$ M_{SUSY} at **TeV**

Infinite distance limits probed by (dS)**ADC** and the **GC could be different,** e.g. for $\mathcal{N} = 1$ SUGRA EFTs with nearly-flat scalar potential.

- ADC: Interpreting Λ (the cosmological constant) as a metric parameter, it gives information about the motion in the geometric space of metrics, ADC claims that the limit $\Lambda \to 0$ is at infinite-distance and is related to an infinite tower of states with masses $m \sim |\Lambda|^{\alpha}$; with $\alpha \sim \mathcal{O}(1)$.

- Our proposal is to use **GC** to connect the **number p** of **mesoscopic EDs** at **size l** to $m_{3/2}$ (i.e. M_{SUSY}).

$l = m_{KK}^{-1}$

Setup

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- We work on **4d $\mathcal{N} = 1$ Supergravity** from type IIA/IIB Calabi-Yau orientifold compactification, where the volume of the internal manifold can be approximated by the one of a $\boldsymbol{p}$**-cycle**, $\mathscr{V}_p$, whose $\boldsymbol{p}$ directions are compactified at the same scale $\boldsymbol{l}$.

$l = m_{KK}^{-1}$

  - $\boldsymbol{l}$ is large, then $\mathscr{V}_p$ **is large**. The others $6 - p$ directions remain small.
  - SUSY is broken, say by F-term.
  - Universal perturbativity condition $\boldsymbol{g_s \lesssim 1}$, where g_s is the 10-dimensional dilaton/string coupling.

In the large volume/large complex structure limit of type IIA/IIB this reads differently [Font, Herráez, Ibáñez '19]

IIA: $g_{(4)} \lesssim 1$

IIB: $g_s \lesssim 1$

Setup

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- We work on **4d $\mathcal{N} = 1$ Supergravity** from type IIA/IIB Calabi-Yau orientifold compactification, where the volume of the internal manifold can be approximated by the one of a ***p*-cycle**, $\mathcal{V}_p$, whose p directions are compactified at the same scale l.

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  - l is large, then $\mathcal{V}_p$ **is large**. The others $6 - p$ directions remain small.
  - SUSY is broken, say by F-term.
  - Universal perturbativity condition $g_s \lesssim 1$, where g_s is the 10-dimensional dilaton/string coupling.

- We refine **GC** relation $m_{KK} \sim (m_{3/2})^n$ by finding by finding **bounds for the parameter n** in terms of the **number p of large EDs.**

- Finally, we present **phenomenological scenarios** relating sections of the parameter spaces of $m_{3/2}$ and l, at varying p.

In this talk:

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1. Introduction

2. **Results**
   - **Supergravity with large p-cycle**
   - **Bounds on the Gravitino Conjecture from large EDs**
   - **Phenomenological scenarios**

Conclusions

Supergravity with large p-cycle

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- We divided the **results** into **three parts**:

1. **Kähler potential modification** when the volume of the internal manifold is dominated by $\mathscr{V}_p$:

IIA-like: $K \simeq -\frac{6}{p} \ln \mathscr{V}_p^{(E)} + \dots$ IIB-like: $K \simeq -\frac{12}{p} \ln \mathscr{V}_p^{(E)} + \dots$

Where (E) means Einstein frame and the dots represent **dilaton-dependent** factors.

This is obtained generalising the usual two-cycle t^i / four-cycle τ^k dependence of the internal volume in type IIA/IIB cases:

$\mathscr{V}_p \sim f_{p/2}(t^i)$ $\mathscr{V}_p \sim f_{p/4}(\tau^k)$

Supergravity with large p-cycle

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Where (E) means Einstein frame and the dots represent **dilaton-dependent** factors.

- The superpotential is assumed at $\partial V/\partial\phi = 0$ as $\langle W \rangle \sim constant$.

Bounds on the GC from large EDs

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2. We find **explicit relations between $m_{3/2}, m_{KK}$, and $\mathcal{V}_p$** :

IIA-like: $$\left(\frac{m_{KK}}{M_{P,(4)}}\right) = \mathcal{V}_p^{-\frac{1}{p}} g_{(4)}\,,$$

IIB-like: $$\left(\frac{m_{KK}}{M_{P,(4)}}\right) = \mathcal{V}_p^{-\frac{1}{p}-\frac{1}{2}} g_s\,,$$

IIA-like: $$\left(\frac{m_{3/2}}{M_{P,(4)}}\right) \sim \mathcal{V}_p^{-\frac{3}{p}} g_{(4)}^2\,,$$

IIB-like: $$\left(\frac{m_{3/2}}{M_{P,(4)}}\right) \sim \mathcal{V}_p^{-\frac{6}{p}} g_s^{\frac{1}{2}}\,.$$

3. We insert this in the **GC** to **find generalised bounds** on n:

IIA-like: $$\frac{1}{3} \leq n \leq \frac{1}{2} + \frac{1}{p}$$

IIB-like: $$\frac{1}{6} + \frac{p}{12} \leq n \leq \frac{1}{2} + \frac{1}{p}$$

- Lower bounds: **perturbative string regime**.
- Upper bounds: $M_{SUSY} \leq \Lambda_{sp}$.

Phenomenological scenarios

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- **Easily detectable scenarios within the next generation of experiments** [Lee, Adelberger, Cook, Fleisher, Heckel '20]

Recall the experimental constraint $l < 38.6\,\mu m$, therefore consider $\boldsymbol{l_* \sim 10^{-7} m}$.

- $\boldsymbol{p = 1}$ and $\boldsymbol{p = 2}$ are the only possibilities at this scale. [Hannestad, Raffelt (v3) '04 ('25)]
- Predictions for both IIA/IIB:

$p = 1$	$n \in \left[1, \frac{3}{2}\right]$	$m_{3/2} \in [0.1\,eV,\ 2.1\,GeV]$	$M_{SUSY} \in [10^4\,GeV,\ 10^9\,GeV]$	$\Lambda_{sp} \sim 10^9\,GeV$
$p = 2$	$n \sim 1$	$m_{3/2} \sim 1.9\,eV$	$M_{SUSY} \sim 7\,TeV$	$\Lambda_{sp} \sim 7\,TeV$

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With just the **GC** as assumption, we recover something similar to the interesting results of:

[Montero, Vafa, Valenzuela '22]

[Anchordoqui, Antoniadis, Lüst '25]

Phenomenological scenarios

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- **Scenarios with larger gravitino mass** $m_{3/2} \sim 10^5\,GeV$

- No bound on the value of p → Scenarios **across all values** of p.
- Values of l are in general very small. For example:

IIB-like case

$$\begin{cases} p = 1 \quad n \in \left[\frac{1}{4}, \frac{3}{2}\right] \quad l \in \left[10^{-31}\,m,\ 10^{-14}\,m\right] \\ p = 2 \quad n \in \left[\frac{1}{3}, 1\right] \quad l \in \left[10^{-30}\,m,\ 10^{-21}\,m\right] \end{cases} \quad \Lambda_{sp} \in \left[10^{16}\,GeV,\ 10^{11}\,GeV\right] \quad M_{SUSY} \sim 10^{11}\,GeV$$

- IIA case very similar

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- Assuming the **GC** we can connect in a **quantitative** way **predictions for M_{SUSY}** to the **existence of p large EDs compactified at a size l** and viceversa.

- We performed calculations considering “1” as proportionality parameter in the GC, so for our results holds $m_{KK} = (m_{3/2})^n$.

- We have many (interesting) phenomenological scenarios. The two cases we presented are associated with two different **mediation mechanisms of SUSY breaking**.

- Just assuming **GC**, for $l_* \sim 10^{-7} m$ we can extend results found also in DD scenario giving predictions for $m_{3/2}$ and M_{SUSY} at the cost of not directly dealing with the cosmological hierarchy problem.

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Thank You!

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Extra slides

Connecting $m_{3/2}$ with EDs - bounds

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- Context: Space with p large extra dimensions in which gravity can propagate.
- Consider the **GC** relation $m_{KK} = \lambda_{3/2}\left(\frac{m_{3/2}}{M_p}\right)^n M_p\,,$ where for us $\lambda_{3/2} = 1$, and (for example) translate **upper bounds on EDs** in lower bounds for $m_{3/2}$.

p-independent bound

$$l \lesssim 38.6\,\mu m$$

[Lee, Adelberger, Cook, Fleisher, Heckel '20]

p values	**upper bounds on l** (in meters)
1	$4.9 \cdot 10^{2}$
2	$0.96 \cdot 10^{-6}$
3	$1.14 \cdot 10^{-9}$
4	$3.82 \cdot 10^{-11}$

[Hannestad, Raffelt (v3) '04 ('25)]

Those are not the most restrictive bounds, and this choice is justified by possibly not considering isometries in the extra dimensions.

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[Hannestad, Raffelt (v3) '04 ('25)]

Lower bound on $m_{3/2}$ from LHC probed energies

$$m_{3/2} > 0.1\,eV$$

[Particle Data Group '22]

- At fixed n or p.

We improve this by finding **bounds for the parameter n** in terms of the **number p of large EDs.**