The gravitino mass and extra dimensions

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IMPRS recruiting workshop, MPP

25 November 2024

1. Introduction

Max-Planck-Institut
für Physik

We need to find a theory of **Quantum Gravity (QG)**.

To unify **Quantum Field Theory (QFT)** and **General Relativity (GR),** and to address difficult fundamental questions such as **Black Hole interior** and **“big bang” singularity**.

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    - **Top-down:** String model-building.
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The structure of QG imposes **strong constraints** at lower energies. → ***Swampland Program*** Vafa 2005

e.g. No global symmetries. Misner, Wheeler 1957

e.g. Quantum break-time of de Sitter. Dvali, Gómes, Zell 2017

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. . . Weak Gravity conjecture

Gravitino Conjecture

Distance conjecture . . .

. . . ADC conjecture

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$$M_{SUSY}$$

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- **Super String Theory** in its simplest formulation comes with two key characteristics:

Supersymmetry (SUSY) → M_{SUSY}

Extra dimensions (EDs) → $m_{kk} = l^{-1}$

Unobserved yet!

The fact we do not have observed those features imposes (experimental) **bounds**!

$$m_{soft} > \mathcal{O}(10)\,TeV$$

Based on LHC results showing no evidence of superpartners. Particle Data Group 2022

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

Derived from tests of Newton's law and no deviations detected. Lee, Adelberger, Cook, Fleisher, Heckel 2020

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- **Super String Theory** in its simplest formulation comes with two key characteristics:

Supersymmetry (SUSY)

$$M^2_{SUSY} \sim m_{3/2} M_{pl}$$

Extra dimensions (EDs)

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

Unobserved yet!

- **The mass of the gravitino** $m_{3/2}$, the supersymmetric partner of the graviton, **sets** the scale of **SUSY breaking** in a quasi-flat spacetime, as observed today.

We are interested in exploring phenomenological connections between $m_{3/2}$ and EDs.

2. Exploring connections

Interesting observation:

The experimental **lower bound** on the **gravitino mass** is of the same order of the **upper bound** on the size of **extra dimensions.**

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

Derived from LHC bounds on m_{soft} .

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- This relationship aligns naturally with a special constraint on the **gravitino mass**:

Cribiori, Lüst, Scalisi 2021
Castellano, Font, Herraez, Ibañez 2021

- The **Gravitino Conjecture (GC):**
  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.

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  - The **gravitino mass** $m_{3/2}$ is linked to the **compactification scale** l:

$$l^{-1} \sim (m_{3/2})^n$$

→ n is an $\mathcal{O}(1)$ parameter.

2.1 Exploring connections

Purposes:

- To **refine the previous relation** by linking the parameter n to the number of **mesoscopic** EDs p.

$p = 1,\ldots,6$

- To **find constraints on** n via **supergravity models.**
- To **draw scenarios** concerning **interesting phenomenological predictions** for the size l and number p of EDs in terms of the **gravitino mass** $m_{3/2}$ and viceversa.

Upshot:

We listed those predictions concerning the **SUSY breaking scale** and **EDs.**

3. Results - Volume dependence

1. Let's assume that the **volume of the internal manifold** is **dominated** by a large p-cycle, $\boldsymbol{\mathscr{V}_p}$.

p equal radii means p large EDs

- The **Kähler potential** is modified:
  - **Type IIA**: $K \simeq -\frac{\mathbf{6}}{\boldsymbol{p}} \ln \mathscr{V}_p + \ldots$
  - **Type IIB**: $K \simeq -\frac{\mathbf{12}}{\boldsymbol{p}} \ln \mathscr{V}_p + \ldots$

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2. Using $l\,, m_{3/2} \propto \mathscr{V}_p$, we refined the relation $l^{-1} \sim (m_{3/2})^n$ to determine $n = n(p)$.

- New **bounds** on n:
  - **Type IIA**: $\frac{1}{3} < n \leq \frac{2+p}{2p}$
  - **Type IIB**: $\frac{2+p}{12} < n \leq \frac{2+p}{2p}$

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

Dvali 2007

3.1 Results - Finding scenarios

3. Drawing scenarios concerning PHENO implications:

- **Easily detectable scenarios within the next generation of experiments**

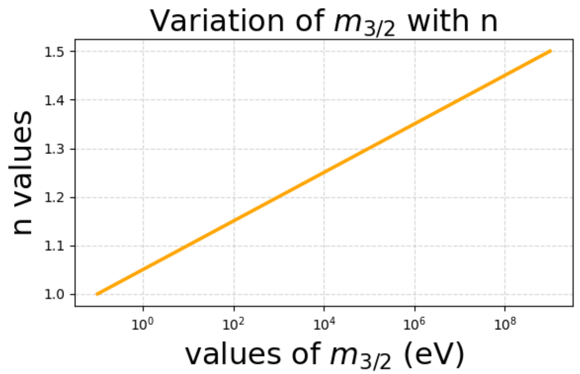
Note: torsion-balance experiments for extra dimensional gravitational signatures like the one in (Lee, Adelberger, Cook, Fleisher, Heckel 2020).

3.1 Results - Finding scenarios

3. Drawing scenarios concerning PHENO implications:

- **Easily detectable scenarios within the next generation of experiments**
  - Recall the experimental constraint $l < 38.6\,\mu m$, therefore consider $l \sim \mu m$.
    - $p = 1$ is the only possibility at this scale. Hannestad, Raffelt 2004
    - Possible range: $1 < n \leq \frac{3}{2}$
    - Predictions: $0.1\,eV \leq m_{3/2} \leq 1\,GeV$ $\quad \Lambda_{sp} \sim 10^9\,GeV$

$$10^4\,GeV \leq M_{SUSY} \leq 10^9\,GeV$$



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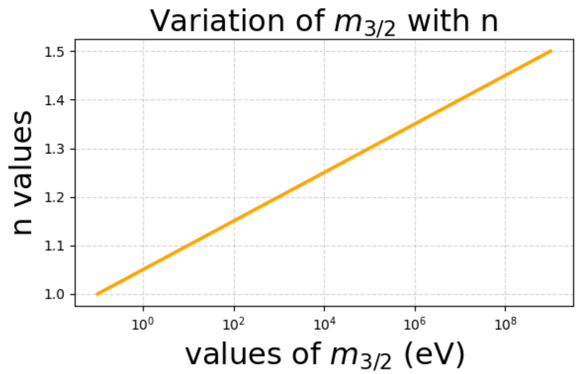

- **Scenarios with larger gravitino mass** $\boldsymbol{m_{3/2} \sim 10^5\,GeV}$
  - Wide range of possible scenarios **across all values** of p.
  - All of them require **small EDs.**

3.1 Results - Finding scenarios

- **Scenarios with larger gravitino mass - Tables**

IIA: $m_{3/2} = 10^5\, GeV$ and $M_{SUSY} = 10^{11}\, GeV$

p values	n values	$l\,(m)$	species scale (GeV)
1	$\frac{1}{3} < n \leq \frac{3}{2}$	$2.32 \cdot 10^{-30} - 9.84 \cdot 10^{-15}$	$8.06 \cdot 10^{16} - 4.98 \cdot 10^{11} \sim M_{SUSY}$
2	$\frac{1}{3} < n \leq 1$	$2.32 \cdot 10^{-30} - 1.98 \cdot 10^{-21}$	$1.45 \cdot 10^{16} - 4.98 \cdot 10^{11}$
3	$\frac{1}{3} < n \leq \frac{5}{6}$	$2.32 \cdot 10^{-30} - 1.16 \cdot 10^{-23}$	$5.19 \cdot 10^{15} - 4.98 \cdot 10^{11}$
4	$\frac{1}{3} < n \leq \frac{3}{4}$	$2.32 \cdot 10^{-30} - 8.86 \cdot 10^{-25}$	$2.62 \cdot 10^{15} - 4.98 \cdot 10^{11}$
5	$\frac{1}{3} < n \leq \frac{7}{10}$	$2.32 \cdot 10^{-30} - 1.89 \cdot 10^{-25}$	$1.60 \cdot 10^{15} - 4.98 \cdot 10^{11}$
6	$\frac{1}{3} < n \leq \frac{2}{3}$	$2.32 \cdot 10^{-30} - 6.78 \cdot 10^{-26}$	$1.11 \cdot 10^{15} - 4.98 \cdot 10^{11}$

IIB: $m_{3/2} = 10^5\, GeV$ and $M_{SUSY} = 10^{11}\, GeV$

p values	n values	$l\,(m)$	species scale (GeV)
1	$\frac{1}{4} < n \leq \frac{3}{2}$	$1.78 \cdot 10^{-31} - 9.84 \cdot 10^{-15}$	$1.90 \cdot 10^{17} - 4.98 \cdot 10^{11} \sim M_{SUSY}$
2	$\frac{1}{3} < n \leq 1$	$2.32 \cdot 10^{-30} - 1.98 \cdot 10^{-21}$	$1.90 \cdot 10^{17} - 4.98 \cdot 10^{11}$
3	$\frac{5}{12} < n \leq \frac{5}{6}$	$3.04 \cdot 10^{-29} - 1.16 \cdot 10^{-23}$	$1.11 \cdot 10^{15} - 4.98 \cdot 10^{11}$
4	$\frac{1}{2} < n \leq \frac{3}{4}$	$3.97 \cdot 10^{-28} - 8.86 \cdot 10^{-25}$	$8.5 \cdot 10^{13} - 4.98 \cdot 10^{11}$
5	$\frac{7}{12} < n \leq \frac{7}{10}$	$5.19 \cdot 10^{-27} - 1.89 \cdot 10^{-25}$	$6.51 \cdot 10^{12} - 4.98 \cdot 10^{11}$
6	$n = \frac{2}{3}$	$6.78 \cdot 10^{-26}$	$4.98 \cdot 10^{11}$

Summary

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- Assuming the **Gravitino Conjecture**:
  - We can make **valuable predictions regarding SUSY** by **observing EDs** and viceversa.
- The connection is exploited by using **String Compactification results**:
  - The internal manifold's volume impacts **Kähler prefactors.**
  - Including $l\,, m_{3/2} \propto \mathscr{V}_p$ in $l^{-1} \sim (m_{3/2})^n$ leads to **bounds on $\boldsymbol{n}$.**
- We collected **Phenomenological implications** in scenarios.
- We performed calculations without considering any proportionality parameter in $l^{-1} \sim (m_{3/2})^n$.

Outlook

- We found phenomenologically interesting scenarios that are similar to the **ADD model**.

Arkani-Hamed, Dimopoulos, Dvali 1998

- In the prediction extrapolated for $p = 1$ and $l \sim \mu m$ we found a phenomenologically viable scenario similar to the **Dark Dimension scenario**.

Montero, Vafa, Valenzuela 2022

- It would be interesting to study how our findings in SUSY-breaking scale may change cosmological predictions (e.g. **Dark Matter candidates**, conditions for **Primordial Black Holes** formation, number of light species).

Obied, Dvorkin, Gonzalo Vafa 2023

Anchordoqui, Antoniadis, Lüst 2022

- It would be interesting to understand **Black Hole instabilities**, such as Gregory-Laflamme, in relation to scenarios with large extra dimensions for possible additional phenomenological constraints.

Thank you for your attention!

This work and other aspects are unpublished yet, [Scalisi, LB, Masias] to appear.

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