The Gravitino and the Swampland

*based on arXiv 2104.08288 in collaboration with **Niccolò Cribiori** and **Dieter Lüst***

Marco Scalisi

MAX-PLANCK-INSTITUT FÜR PHYSIK

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DISCLAIMER!

Our work is **does not directly contribute** to the discussion of

recent investigations about gravitino physics on de Sitter backgrounds:

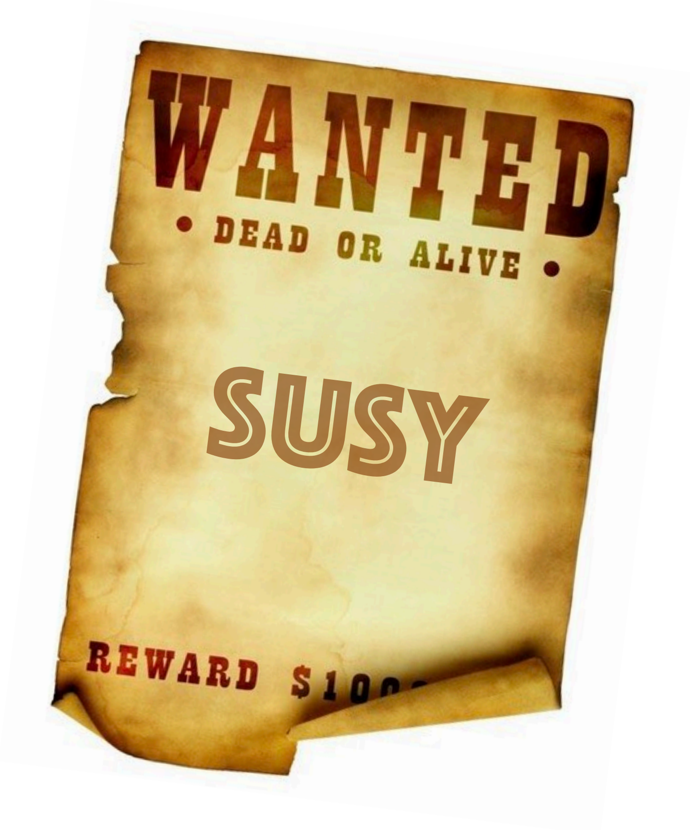
- *2x Kolb, Long, McDonough 2021* → Evan's talk on Apr 13
- *Dudas, Garcia, Mambrini, Olive, Peloso, Verner 2021*
- *Terada 2021*

Outline

- Motivations
- The Gravitino Mass Conjecture
- Tests of the GMC
- Phenomenological implications of the GMC
- Conclusions

Outline

No SUSY so far!



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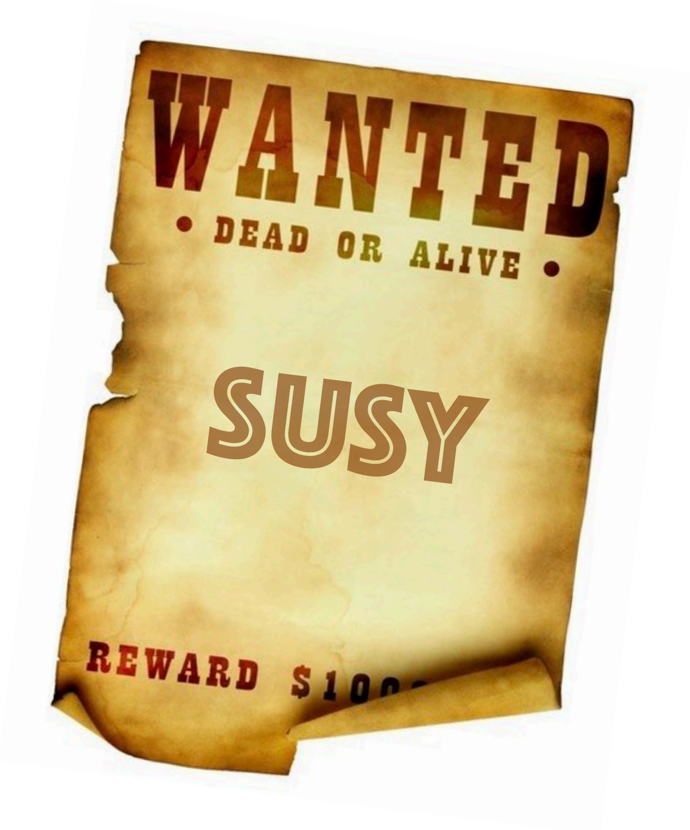
at present

$$\boxed{M_{SUSY}^2 \simeq m_{3/2}\, M_P}$$



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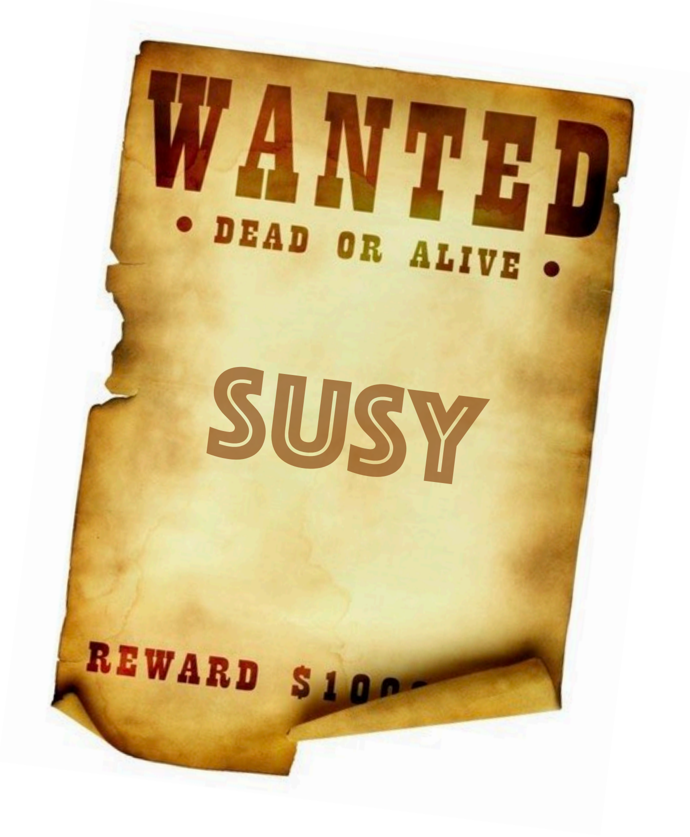

no definite indication on **expected mass range of** $m_{3/2}$ (besides model-dependent results)

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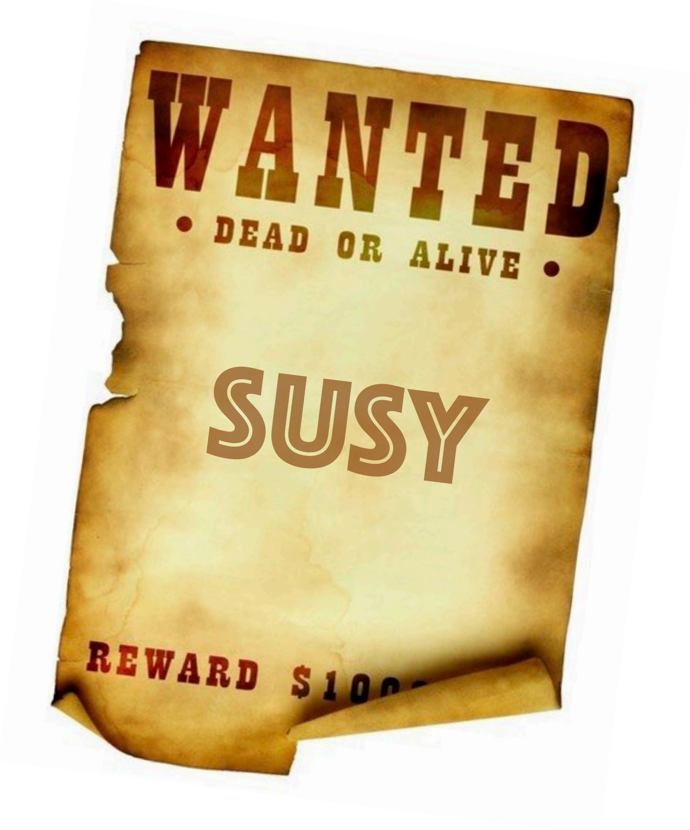

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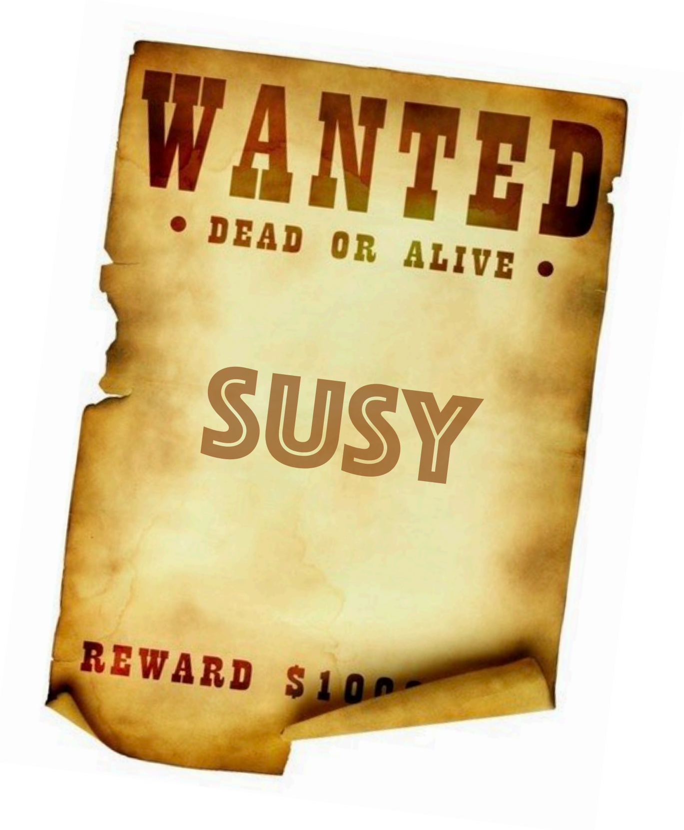

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Swampland

Vafa 2006

Ooguri, Vafa 2006

(reviews)

Palti 2019

Beest, Calderon-Infante, Mirfendereski, Valenzuela

Gravitino Mass Conjecture (GMC)

Outline

The Gravitino Mass Conjecture (GMC)

The limit of **small gravitino mass**

$$m_{3/2} \to 0$$

always corresponds to the **massless limit of an infinite tower of states** and to the breakdown of the effective field theory.

The Gravitino Mass Conjecture (GMC)

such a limit would be at **infinite distance**

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Evidences of infinite tower mass related to $m_{3/2}$

Antoniadis, Bachas, Lewellen, Tomaras 1988

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$$m \sim \left(m_{3/2}\right)^n$$

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generic dependence of the mass tower

$$m \sim \left(m_{3/2}\right)^n$$

$$n = \mathcal{O}(1)$$

$$n = 1$$

Strong GMC

Corrections to this simple scaling might be possible but still satisfying the GMC

e.g. for log corrections

Blumenhagen, Brinkmann, Makridou 2019

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Palti 2020

The GMC and the Anti-de Sitter Distance Conjecture

AdS Distance Conjecture (ADC)

Lüst, Palti, Vafa 2019

The limit of small AdS cosmological constant

$$|\Lambda| \to 0$$

is accompanied by a light infinite tower with mass

$$m \sim \left|\Lambda\right|^{a}$$

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for **SUSY AdS** vacua

$$m_{3/2}^2 = -\frac{\Lambda}{3}$$

GMC = ADC

$$n = 2a$$

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for **non-SUSY AdS** vacua

$$m_{3/2}^2 > -\frac{\Lambda}{3}$$

GMC $\neq$ ADC

however

$m_{3/2} \to 0$ implies $\Lambda \to 0$

i.e. GMC $\to$ ADC

(in AdS space!)

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however

$m_{3/2} \to 0$ implies $\Lambda \to 0$

i.e. GMC → ADC

(in AdS space!)

⚠ No EFT with finite number of fields interpolating AdS, Minkowski and dS

⚠ Extension of the **ADC** to **de Sitter space** implies that there should be a tower with mass

$$m \sim 10^{-120a}$$

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$\mathcal{N}=1$ $D=4$ Effective action and the GMC

The scalar potential is given by

Cremmer, Ferrara, Girardello, Van Proeyen 1983

$$V = V_F + V_D - 3m_{3/2}^2$$

with $m_{3/2} = e^{K(\phi,\bar{\phi})/2}\,|\,W(\phi)\,|$

with V_F and V_D being the **supersymmetry breaking terms**

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$$\boxed{m_{3/2}^2 \geq -\frac{V}{3}}$$

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$$\boxed{m_{3/2}^2 \geq -\frac{V}{3}}$$

it looks like the **analogous** of the **Higuchi bound**

Higuchi 1987

it follows also from requiring **unitarity propagation** and hold more generally than $N=1$ SUGRA

Deser, Waldron 2001

Zinoviev 2007

$\mathcal{N} = 1 \;\; D = 4$ Effective action and the GMC

- We identify the tower with the **Kaluza-Klein** (KK) **states**, with mass

$$m_{KK} = \left(\frac{1}{\mathcal{V}}\right)^{2/3}$$

for **isotropic** manifolds

with $\mathcal{V}$ being the **internal 6-dimensional volume**

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- **Kähler potential** and **super-potential**

$$K(\phi, \bar{\phi}) = -\,\alpha \log \mathcal{V}(\phi, \bar{\phi}) + K'$$

remaining part dependent on
the **complex structure moduli** and on the **dilaton**

$$\langle W \rangle \sim \mathcal{V}^{\beta/2}$$

scaling at the minimum of the potential

$\mathcal{N}=1$ $D=4$ Effective action and the GMC

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scaling at the minimum of the potential

- **Gravitino mass**

$$\boxed{m_{3/2}\sim\left(\frac{1}{\mathscr{V}}\right)^{\frac{\alpha-\beta}{2}}}\quad m\sim\left(m_{3/2}\right)^{n}\quad\boxed{n=\frac{4}{3(\alpha-\beta)}}$$

$\mathcal{N}=1$ $D=4$ Examples

Anti-de Sitter

- For background $AdS_d \times S^{d'}$ $\dashrightarrow$ $\boxed{n=1}$

$\mathcal{N} = 1\ \ D = 4$ Examples

Anti-de Sitter

- For background $AdS_d \times S^{d'}$ ⇢ $\boxed{n = 1}$

- **Supersymmetric IIB AdS vacua (KKLT)** *Kachru, Kallosh Linde, Trivedi 2003*

$$K = -3\log(T+\bar{T}) + \ldots = -2\log\mathcal{V} + \ldots \qquad \langle W \rangle \sim Te^{-cT}$$

$$\mathcal{V} = (\mathrm{Re}T)^{3/2}$$

$$\boxed{\alpha = 2 \qquad \beta = 4/3 \qquad n = 2}$$

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⚠ isotropic scaling of the KK masses not valid! $\dashrightarrow$ $m \sim \left(m_{3/2}\right)^{1/3} \times$ **log corrections**

Blumenhagen, Brinkmann, Makridou 2019
Bena, Dudas, Grana, Lüst 2018
Blumenhagen, Kläwer, Schlechter 2019

$$\boxed{n = 1/3}$$

$\mathcal{N} = 1$ $D = 4$ Examples

Anti-de Sitter

- **Non-SUSY IIB AdS vacuum (Large Volume Scenario)** *Balasubramanian, Berglund, Conlon, Quevedo 2005*

$$K = -2\log(\mathscr{V} + \xi/2) \qquad W \sim W_0 + \text{non-perturbative terms}$$

can be order one

$$\alpha = 2 \qquad \beta = 0 \qquad n = 2/3$$

$$m_{3/2} \sim \frac{1}{\mathscr{V}}$$

⚠ non-perturbative contributions to W leads to log-corrections in the KK masses in terms of the cosmological constant

Blumenhagen, Brinkmann, Makridou 2019

$\mathcal{N}=1$ $D=4$ Examples

Minkowski

- **No-scale models**

  Cremmer, Ferrara, Kounnas, Nanopoulos 1983
  Ellis, Kounnas, Nanopoulos 1984

$$K = -3\log(T+\bar{T}) \qquad W = \text{const}$$

  - for heterotic string compactifications $\mathscr{V} = (T+\bar{T})^3$ → $\boxed{\alpha = 1 \quad \beta = 0 \quad n = 4/3}$
  - for type IIB GKP orientifolds $\mathscr{V} = (T+\bar{T})^{3/2}$ → $\boxed{\alpha = 2 \quad \beta = 0 \quad n = 2/3}$

- **Scherk-Schwarz models** *Scherk, Schwarz 1979*
- **No-scale models with F-term and D-term** *Dall'Agata, Zwirner 2013*

$\mathcal{N} = 1 \;\; D = 4$ Examples

de Sitter

GMC in de Sitter can also be supported by its **validity in anti-de Sitter spaces**

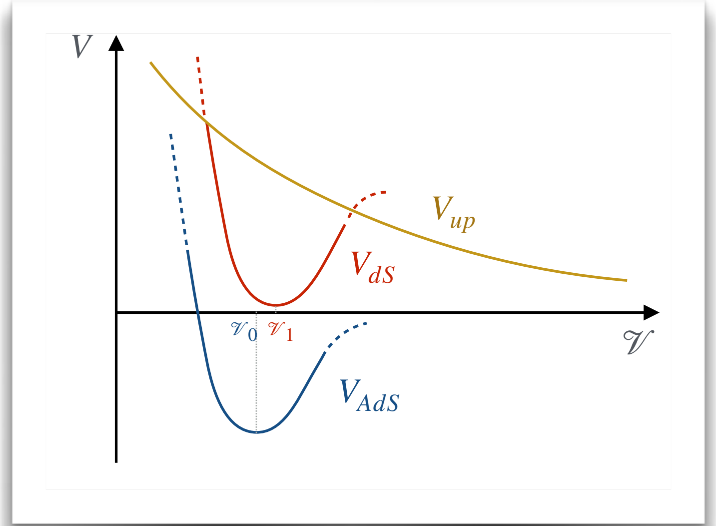
Some of the best and most studied dS constructions have

$$V_{dS} = V_{AdS} + V_{up} \qquad \text{with} \quad V_{up} = \frac{c}{\mathcal{V}^p}$$

Kachru, Kallosh Linde, Trivedi 2003

Balasubramanian, Berglund, Conlon, Quevedo 2005

Westphal 2006



$$\delta\mathcal{V} \ll 1$$

$$\boxed{m_{3/2}(\mathcal{V}_1) \simeq m_{3/2}(\mathcal{V}_0)}$$

consequences of the **GMC in de Sitter** directly **follow from** the discussion of the **GMC in anti-de Sitter**

$\mathcal{N} = 2 \;\; D = 4$ Effective Action and the GMC

Content: spin-2 graviton $g_{\mu\nu}$, **two spin-3/2 gravitini** ψ_μ^A , spin-1 graviphoton A_μ^0, vector- and hyper-multiplets

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We find a **relation** between the **gravitino mass** and the **gravitino gauge coupling**

$$\boxed{g_{3/2} = e^{\frac{K}{2}} \, \mathscr{F}(z, q)}$$

$\mathscr{F}(z, q)$ = model-dependent function of the scalar fields

$e^{\frac{K}{2}} \sim \mathscr{V}^{-\frac{\alpha}{2}}$

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implies

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and

restoration of global symmetries

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Example: **STU model**

$$K = -\log(stu)$$

$$S_{AB} = = \frac{i}{2\sqrt{2}} q_{3/2} \; g_{3/2} \; \mathrm{diag}(1, -1)$$

$$m_{3/2} \to 0 \quad \Leftrightarrow \quad g_{3/2} \to 0$$

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Gravitino and Quantum Gravity Cut-off

$$\Lambda_{QG} = \frac{M_P}{\sqrt{N}}$$

quantum gravity cut-off = "species scale"

Dvali 2007

Dvali, Redi 2007

$$N = \frac{\Lambda_{QG}}{m}$$

number of states below the cut-off

in the case of states equally spaced (as for KK or winding modes)

$$m \sim M_P \left(\frac{m_{3/2}}{M_P}\right)^n$$

mass of the tower

Gravitino and Quantum Gravity Cut-off

- The mass of the gravitino **sets the quantum gravity cut-off**

$$\boxed{\Lambda_{QG} \simeq M_P \left(\frac{m_{3/2}}{M_P}\right)^{\frac{n}{3}}}$$

- The mass of the gravitino **depends on the number of states** with mass under Λ_{QG}

$$\boxed{m_{3/2} \simeq \frac{M_P}{N^{\frac{3}{2n}}}}$$

$m_{3/2} < \Lambda_{QG}$ if $n < 3$

for $n \geq 3$, **no EFT of SUSY breaking**!

For the strong GMC ($n = 1$)

$$m_{3/2} \simeq \frac{M_P}{N^{\frac{3}{2}}} = \frac{\Lambda_{QG}^3}{M_P^2} < \Lambda_{QG}$$

Gravitino and Quantum Gravity Cut-off

- In the case of a **charged gravitino**

$$\Lambda_{QG} < g_{3/2}\, M_P$$

imposed by **magnetic WGC**

using the expression for the cut-off $\Lambda_{QG} \simeq M_P \left(\frac{m_{3/2}}{M_P}\right)^{\frac{n}{3}}$

$$m_{3/2} < (g_{3/2})^{3/n} M_P < g_{3/2}\, M_P$$

of the form suggested by the **electric WGC**

(if $n < 3$ and assuming $g_{3/2} < 1$)

Gravitino and (Quasi-)de Sitter Space

Perturbative control of our EFT of de Sitter requires

$$\Lambda_{QG} > H$$

using the expression for the cut-off $\Lambda_{QG} \simeq M_P \left(\frac{m_{3/2}}{M_P}\right)^{\frac{n}{3}}$

$$\boxed{m_{3/2} > M_P^{\frac{n-3}{n}} H^{\frac{3}{n}}}$$

model-independent lower bound on the gravitino mass in terms of the Hubble parameter

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model-independent lower bound on the gravitino mass in terms of the Hubble parameter

for $n = 3$

- explicit dependence from M_P drops
- **we recover** $\boxed{m_{3/2} > H}$
- but, no EFT of SUSY breaking!

"catastrophic" gravitino production

Kolb, Long, McDonough 2021

volume destabilization in KKLT

Kallosh, Linde 2004

A lower bound on $m_{3/2}$ from CMB

In the **slow-roll approximation**

$$H = \sqrt{\frac{\pi^2 A_s\, r}{2}} M_P \simeq 10^{-4}\sqrt{r}\; M_P$$

the bound $m_{3/2} > M_P^{\frac{n-3}{n}} H^{\frac{3}{n}}$ becomes

$$\boxed{m_{3/2} > \left(10^{-12}\; r^{\frac{3}{2}}\right)^{\frac{1}{n}} \; M_P}$$

lower bound on the gravitino mass
in terms of the **tensor-to-scalar ratio** r

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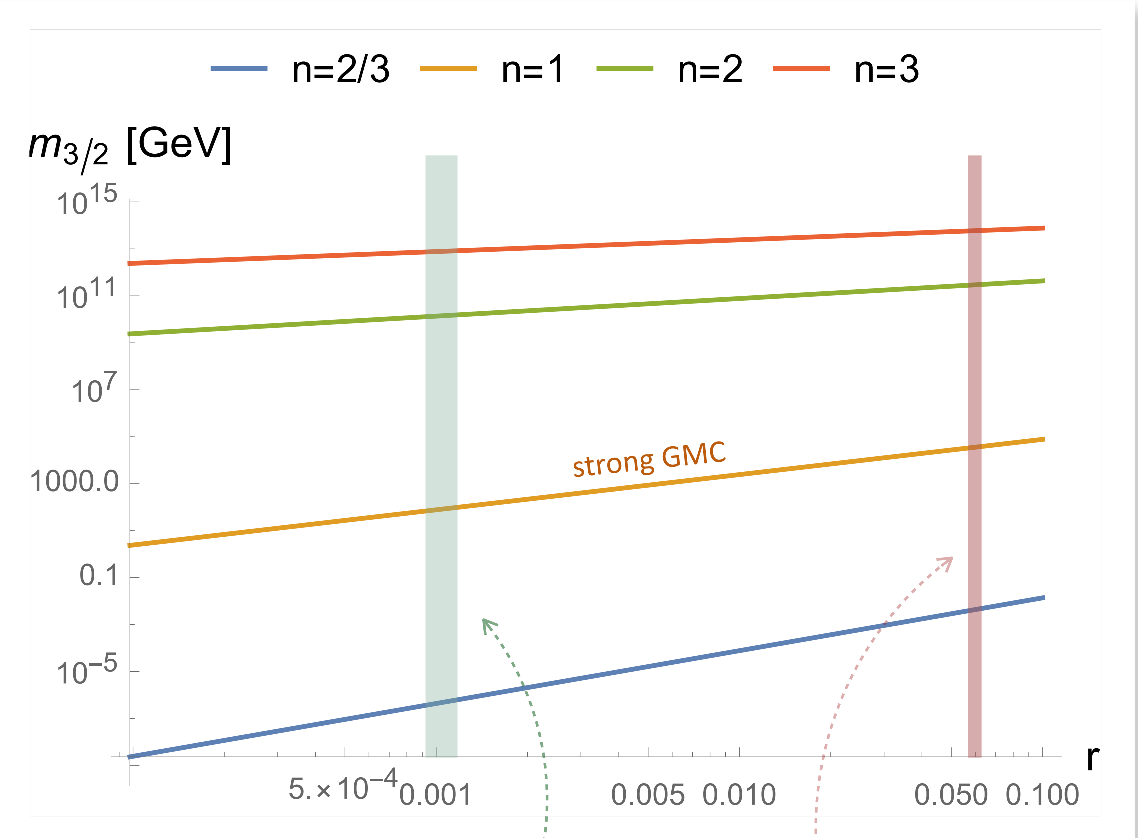
(log-log Plot)



$r = \mathcal{O}(10^{-3})$
future target of **CMB-S4** and **The Simons Observatory**

(for n=1) **any detection of B-modes would point at**

$m_{3/2} \gtrsim 10$ GeV

$r \lesssim 0.06$
upper bound set by **Planck**

(for n=1) the eventuality of detection of the highest compatible r would mean

$m_{3/2} \gtrsim 10^2$ TeV

An upper bound on the scalar field range in terms of $m_{3/2}$

If the quasi-de Sitter phase is **sustained by a scalar field displacement,**

the **Swampland Distance Conjecture** (SDC) predicts *Ooguri, Vafa 2006*

$$\Lambda_{QG} = \Lambda_0 \, e^{-\lambda \Delta\phi}$$

with $\Lambda_0 \leq M_P$ original naive cut-off of the EFT

$$\Delta\phi < \frac{1}{\lambda} \log \frac{M_P}{\Lambda_{QG}}$$

see for example *MS, Valenzuela 2018*

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$$\boxed{\Delta\phi < \frac{n}{3\lambda} \log \frac{M_P}{m_{3/2}}}$$

for $n \simeq \lambda \simeq 1$, it **constrains large scalar field variations** (*i.e.* $\Delta\phi > 1$) just for very high values of the gravitino mass close to the Planck scale

$$m_{3/2} > 10^{-2} M_P$$

Gravitino coupling constant and Hubble parameter

Montero, Van Riet and *Venken* have shown the existence of a *Montero, Van Riet, Venken 2019*

lower bound on the mass of a charged particle in de Sitter space.

In the case of the gravitino, it reads

$$m_{3/2} > \sqrt{q_{3/2}\ g_{3/2}\ M_P H}$$

using $m_{3/2} < (g_{3/2})^{3/n} M_P$ and taking $n = 1$

$$\boxed{\frac{g_{3/2}^5}{q_{3/2}} > \frac{H}{M_P}}$$

bound stronger than the one obtained from the **magnetic WGC**

$$H < \Lambda_{QG} < g_{3/2}\ M_P$$

detection of B-modes in next generation CMB experiments

would point at a bound $\boxed{g_{3/2} \gtrsim 0.08}$

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Conclusions

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stating that

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in **AdS**, **Minkowski** and **dS**

We have derived **pheno implications** in

quasi-dS backgrounds

$$m_{3/2} \gtrsim 10 \text{ GeV}$$

Conclusions

thanks!

We have proposed the

Gravitino Mass Conjecture

stating that

the limit of small gravitino mass

$$m_{3/2} \to 0$$

corresponds to the massless limit of an

infinite tower of states and

the break-down of the EFT

we have focused mainly on

$$m \sim \left(m_{3/2}\right)^n$$

We have discussed **differences** and

similarities of the

Gravitino Mass Conjecture

and the **AdS Distance Conjecture**

We have tested the GMC in a number of

examples of string compactification to D=4

in **AdS**, **Minkowski** and **dS**

We have derived **pheno implications** in

quasi-dS backgrounds

$$m_{3/2} \gtrsim 10 \text{ GeV}$$