


The Gravitino and the Swampland

DIETER LÜST (LMU, MPP)

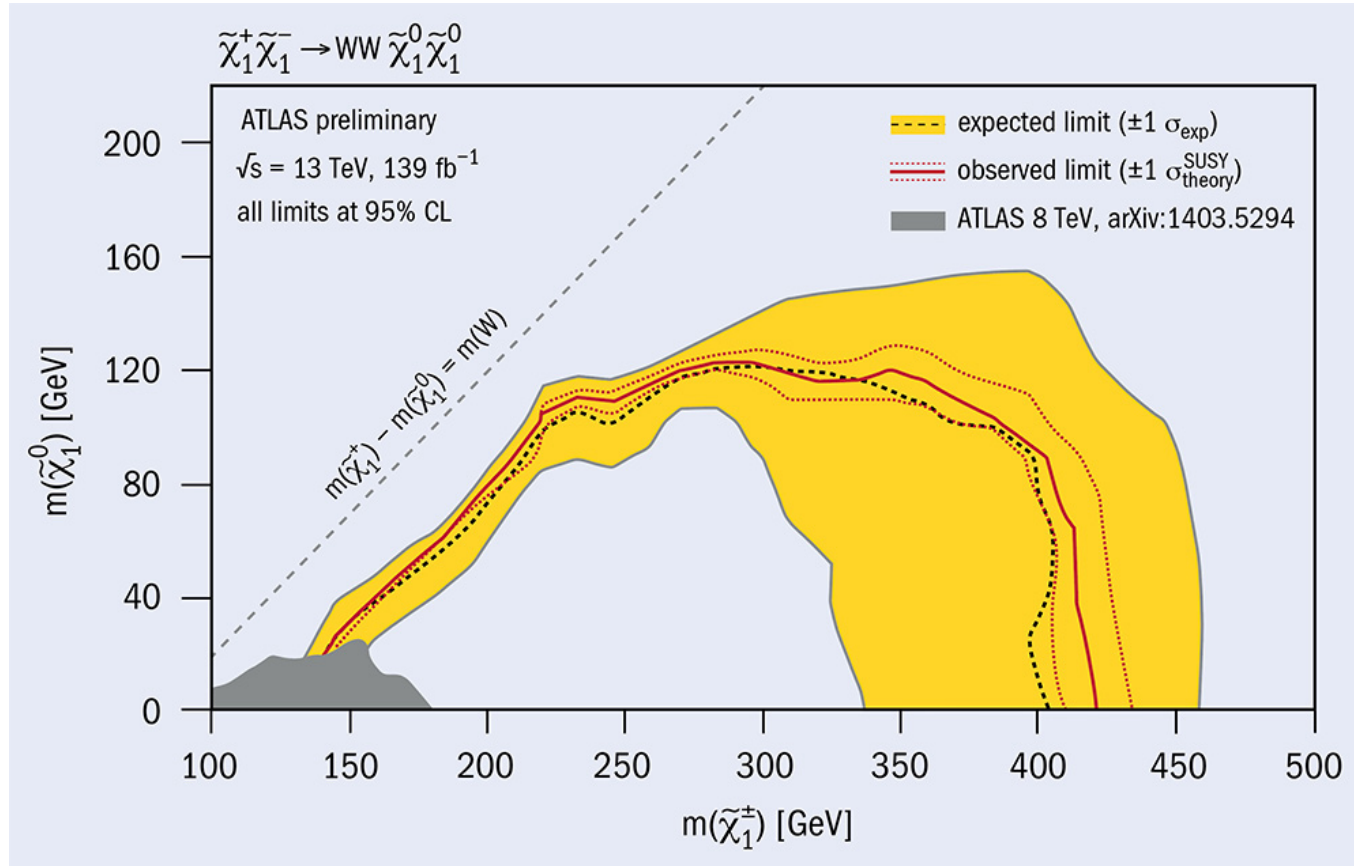


Joint work with Niccolo Scribiori and Marco Scalisi,
arXiv:2104.08288, JHEP 06 (2021) 071

I) Introduction

Apparently low energy supersymmetry is not favoured by experiments:

$$M(\text{Susy partner}) > \mathcal{O}(TeV)$$



Is there any fundamental reason against low energy supersymmetry ??

$\mathcal{N} = 1$ local supersymmetry:

Spin - 2 graviton \longleftrightarrow Spin - 3/2 gravitino
Susy

The scale of susy breaking is set by the gravitino:

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

Exp: $m_{3/2} \geq \mathcal{O}(10^{-3} \text{eV})$

Is there any fundamental reason against a light gravitino ??

Here we like to ask the question:

Can we get information about the scale of Susy breaking, i.e. about the mass of the gravitino from basic properties of quantum gravity ?

Similar question can be asked for

- the mass of the graviton or higher spin particles

[D. Kläwer, D.L. , E. Palti (2018)]

- the cosmological constant

[G. Dvali, C. Gomez (2013/2014);
G. Obied, H. Ooguri, L. Spodyneiko, C. Vafa (2018)]

- Fermions and the swampland

[E. Palti (2020)]

- the number of space-time dimensions

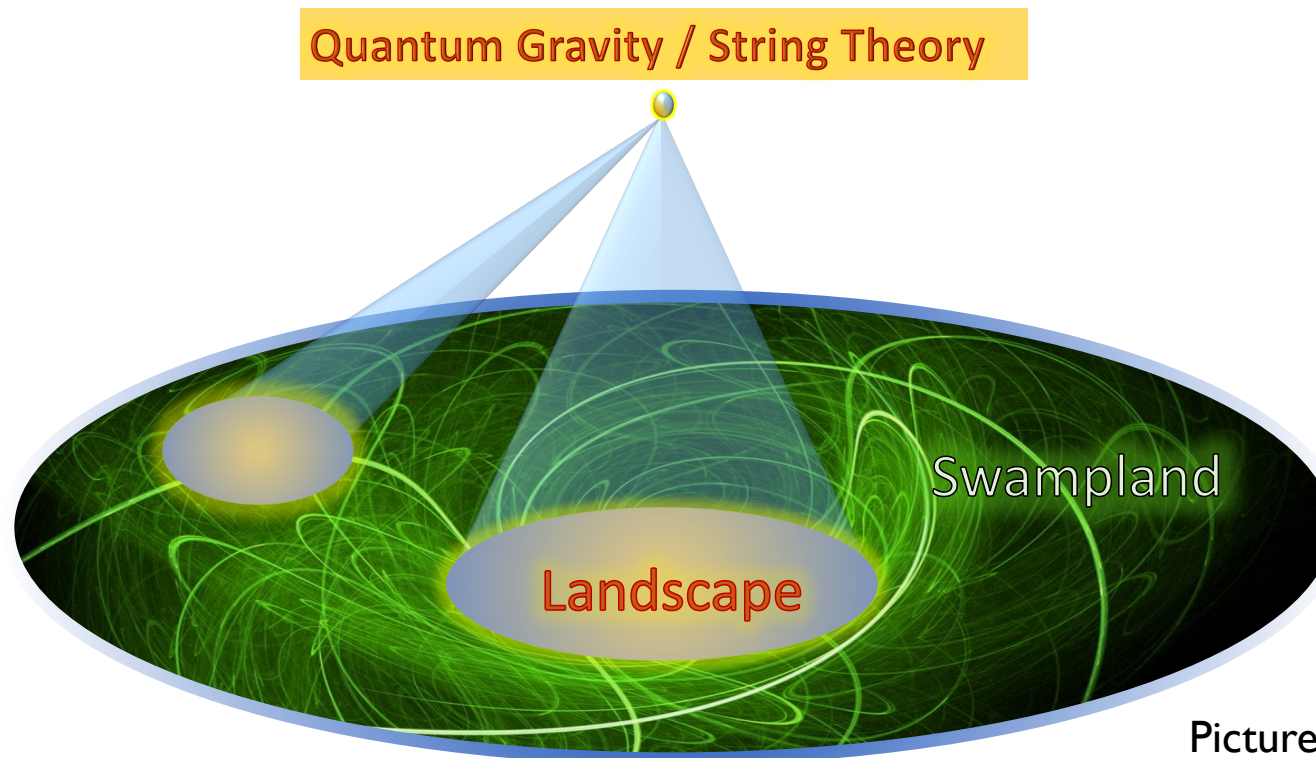
[Q. Bonnefoy, L. Ciambelli, D.L. , S. Lüst (2020)]

Swampland program:

[H. Ooguri, C.Vafa (2006)]

[Reviews by E. Palti (2019)
M. van Beest, J. Calderon-Infante, D.
Mirfendereski, I.Valenzuela (2021)]

Which IR consistent quantum field theories cannot be embedded into a UV complete quantum gravity theory?



Picture thanks to Eran Palti

Outline:

II) Some swampland conjectures

III) AdS distance conjecture

IV) Gravitino mass conjecture

V) Phenomenological consequences

II) Some swampland conjectures

Weak gravity conjecture:

[N.Arkani-Hamed, L. Motl, A. Nicolis, C.Vafa (2007)]

$$S = \int d^4x \sqrt{-g} \left(\frac{M_p}{2} R - \frac{1}{4g_{U(1)}^2} F^2 \right)$$

Electric version:

There always exists a particle in the theory with mass m and charge q , satisfying

$$m_q \leq g_{U(1)} |q| M_p$$

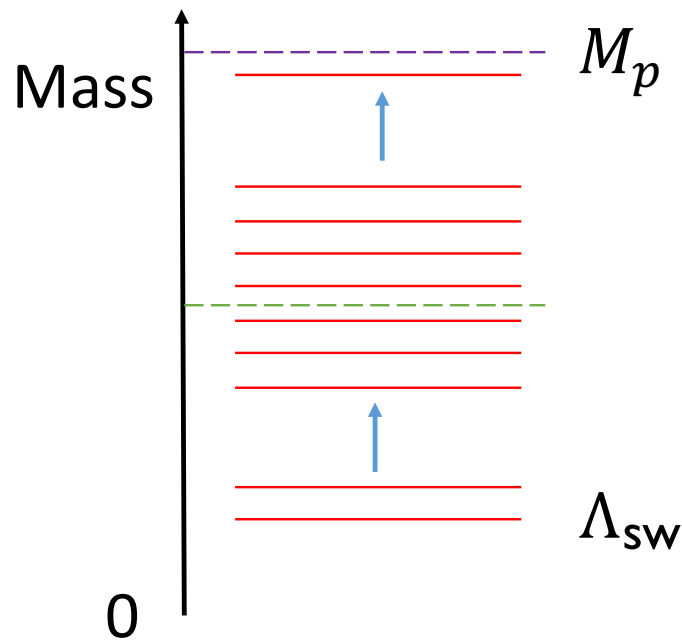
Magnetic version:

Cut-off of the effective theory is bounded from above as $\Lambda \leq g_{U(1)} M_P$

EFT typically breaks down above a swampland scale Λ_{sw} .

If swampland scale Λ_{sw} is lower than any characteristic energy scale of the EFT then the entire EFT belongs to the swampland.

Often there is an (infinite) tower of states above $E \geq \Lambda_{sw}$



Swampland distance conjecture:

At large distance Δ directions in the parameter space of string vacua there must be an infinite tower of states with mass scale m .

SDC:

$$m = M_P e^{-\Delta}$$

[H. Ooguri, C. Vafa (2006)]

EFT breaks down at $\Lambda_{sw} \equiv m$.

$$\Lambda_{sw} \ll M_P \quad \text{when} \quad \Delta \rightarrow \infty$$

In general Δ determines the geodesic distance in the ϕ - parameter space of backgrounds in gravity: $\Delta = \Delta(\phi)$

$$\mathcal{L}_{eff} \simeq \frac{1}{2} (\partial\Phi)^2 + (V(\Phi)) \quad \text{with} \quad \Phi = \Phi(\phi)$$

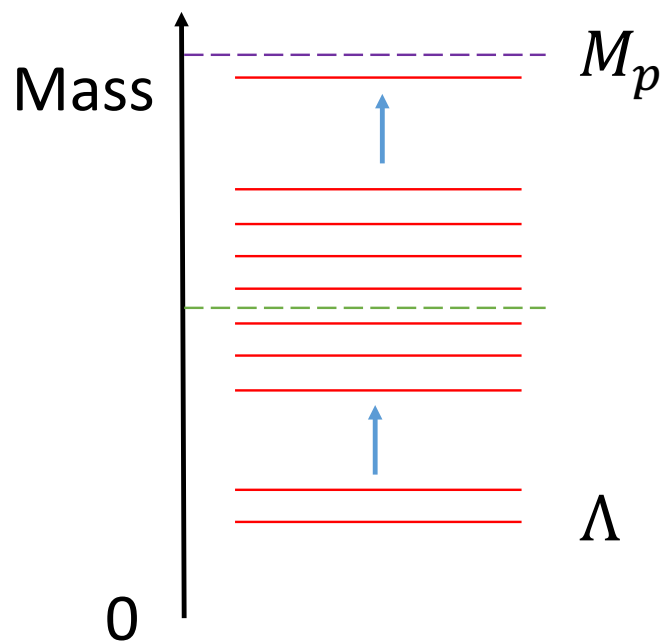
$$\implies \Delta = \lambda \Phi$$

For (string) compactifications the SDC is often due to the higher dimensional nature of theory:

At the KK mass scale a new dimension is opening up.

For a compact circle of radius R , the relevant mass scale is

$$m = m_{KK} = 1/R, \quad \Delta_{KK}(R) = \log R$$



The relevant tower are the **KK particles** with masses

$$m_n = \frac{n}{R}$$

and also with U(1) gauge couplings

$$g_{U(1)} = \frac{1}{R}$$

Quantum gravity/string vacua are normally characterised by several parameters, like masses or other couplings,

$$g = g(\phi), \quad m = m(\phi)$$

and we like to know, what is happening in certain (infinite distance) limits, e.g.

$$g \rightarrow 0 \quad \text{or} \quad m \rightarrow 0$$

and in particular, if these limits are obstructed in quantum gravity in the sense that they related to lowering the cut-off of the theory and are accompanied by a tower of light states.

III) AdS distance conjecture:

Consider AdS_d vacua in quantum gravity with varying negative cosmological constant Λ_{cc} .

AdS Distance conjecture (ADC):

[D.L., E. Palti, C.Vafa (2019)]

There exist an infinite tower of states with mass scale m , which behaves as

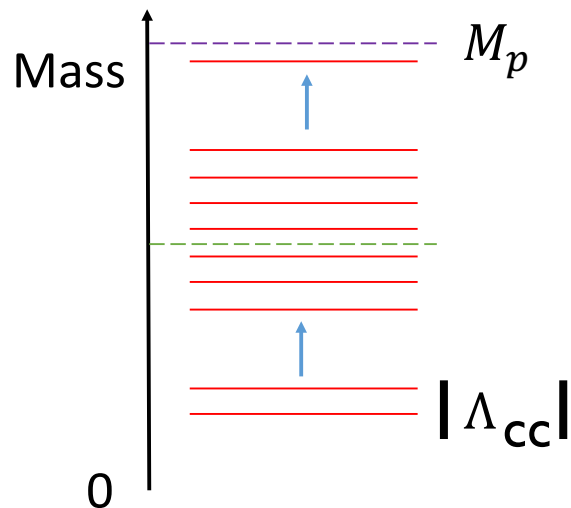
$$m \sim |\Lambda_{cc}|^\alpha \quad \text{with} \quad \alpha \geq \frac{1}{2}$$

AdS_d alone cannot exist as consistent background.
(Interesting implications for dual CFT description!)

[L.Alday, E- Perlmutter (2019), E. Perlmutter, L. Rastelli, C.Vafa, I.Valenzuela (2020)]

Strong AdS distance conjecture (SADC):

The bound $\alpha = 1/2$ is saturated for supersymmetric AdS vacua.



Infinite tower of states above Λ_{cc}

The conjecture is satisfied for many known backgrounds of string and M - theory like $AdS_5 \times S^5$ via the tower of KK modes.

Consider (meta-stable) vacua with positive cosmological constant and assume that the ADC is still valid :

Then, in the standard cosmological scenario, the ADC leads to a very strong prediction, namely to a very light tower of states:

$$m \sim 10^{-120\alpha} \quad (\text{in Planck units})$$

What could be this tower of states, and if it exists, can it escape observations?

Perhaps we need to refine the ADC for broken supersymmetry and also for vacua with $\Lambda_{cc} \geq 0$.

Gravitino mass conjecture (GMC):

[N. Cribiori, M. Scalisi, D.L. ; A. Castellano, A. Font, A. Harraez, L. Ibanez (2021)]

In the limit of small gravitino mass there exist an infinite tower of states with mass scale m , which behaves as:

$$m \sim (m_{3/2})^n \quad \text{with} \quad n > 0$$

For supersymmetric AdS spaces one has that

$$(m_{3/2})^2 = -\frac{\Lambda_{cc}}{3}$$

and the ADC and the GMC are equivalent to each other.

(Note that the case $m_{3/2} = 0$ is special and not continuously related to finite $m_{3/2}$.)

But in case of **broken supersymmetry** one has that

$$(m_{3/2})^2 > -\frac{\Lambda_{cc}}{3}$$

and the ADC and the GMC lead to different conclusions.

In particular the GMC allows for

$$|\Lambda_{cc}| \rightarrow 0 \quad \text{and} \quad m_{3/2} \text{ finite}$$

and without a tower of light states.

Why the GMC can be true:

(i) The gravitino mass is related to extra dimensions

The GMC follows from the distance conjecture.

(ii) The gravitino mass is related to a $U(1)$ gauge coupling

The GMC follows from the (magnetic) weak gravity conjecture.

(i) Extra dimensions

[See also I. Antoniadis, C. Bachas, D. Lewellen, T. Tomaras (1988)]

The $\mathcal{N} = 1$ effective action contains besides the graviton and the gravitino also a certain number of scalars ϕ (as well as their fermionic superpartners).

ϕ : Moduli parameters of the compactification

Their couplings in the effective action are determined by

[E. Cremmer, S. Ferrara, L. Girardello, A. Van Proeyen (1983)]

Kähler potential: $K(\phi, \bar{\phi})$

Superpotential: $W(\phi)$

Kinetic terms of scalars:

$$\mathcal{L}_{eff} \simeq \frac{1}{2} K_{i\bar{j}} \partial\phi_i \partial\bar{\phi}_{\bar{j}} + c.c$$

Supersymmetry breaking:

F-terms: $F_i \equiv e^{G/2} G_i = e^{K/2} |W| \left(K_i + \frac{W_i}{W} \right) \neq 0$

$$G(\phi, \bar{\phi}) = K(\phi, \bar{\phi}) + \log |W(\phi)|^2$$

Gravitino mass

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

Scalar potential (cosmological constant):

$$V \equiv \Lambda_{cc} = V_G + V_F$$

$$V_G = -3e^G = -3e^K |W|^2 = -3(m_{3/2})^2$$

$$V_F = e^G G^{i\bar{j}} G_i G_{\bar{j}} \geq 0, \quad \implies \quad (m_{3/2})^2 \geq -\frac{\Lambda_{cc}}{3}$$

Consider a (string) compactification from 10 to 4 space-time dimensions on a compact (Calabi-Yau) space with volume \mathcal{V} .

KK mass scale:

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

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

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

$$\implies m_{3/2} \sim \left(\frac{1}{\mathcal{V}} \right)^{\frac{\alpha - \beta}{2}} \quad \text{Hence} \quad n = \frac{4}{3(\alpha - \beta)}$$

Supersymmetric (KKLT) AdS vacua: [S. Kachru, R. Kallosh, A. Linde, S. Trivedi (2003)]

$$K = -3 \log(T + \bar{T}) + \dots = -2 \log \mathcal{V} + \dots$$

$$\langle W \rangle \sim T e^{-cT} \quad n = 1/3$$

Effective field theory on warped throat \rightarrow log corrections

[I. Bena, E. Dudas, M. Grana, S. Lüst (2018); R. Blumenhagen, M. Brinkmann, A. Makridou (2019)]

Non-supersymmetric Minkowski vacua (Scherk-Schwarz):

[J. Scherk, J. Schwarz (1979); E. Cremmer, S. Ferrara, C. Kounnas, D. Nanopoulos (1983), R. Rohm (1984)]

$$K = -\log[(S + \bar{S})(T + \bar{T})(U + \bar{U})] + K'(\phi, \bar{\phi})$$

$$W = \text{const} \quad n = 4/3$$

Non-supersymmetric dS: anti-brane uplift

[G. Dvali, H. Tye (1998); S. Kachru, R. Kallosh, A. Linde, S. Trivedi (2003)]

$$V_{dS} = V_{AdS} + V_{up}, \quad V_{up} = \frac{c}{\mathcal{V}^p} \quad n = 1/3$$

(ii) U(1) gauge coupling

In case there is an underlying extended space-time supersymmetric, the gravitino is charged under an U(1) gauge symmetry.

E.g. $\mathcal{N} = 2$ supersymmetry:

Extended supergravity supermultiplet:

(Spin-2, spin-3/2, spin-1)

↑
Graviphoton U(1) gauge boson

Prepotential:

$$m_{3/2} \simeq g_{3/2}$$

[Also using
A. Ceresole, R. D' Auria, S. Ferrara (1995)]

$$g_{3/2} \rightarrow 0 \implies m_{3/2} \rightarrow 0$$

Global symmetry !

[The relation between the gravitino mass, de Sitter and the WGC was also discussed by N. Cribiori, G. Dall'Agata, F. Farakos(2020)]

V) Applications:

(i) Quantum gravity cutoff in an EFT with susy breaking.

N: number of light species in an EFT.

Gravity becomes strongly coupled at the species scale.

[G. Dvali (2007)]

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

If species are built by the tower of states we get $N = \frac{\Lambda_{QG}}{m}$

For the gravitino mass conjecture we then get

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

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

$$n \geq 3 \implies$$

No effective field theory of supersymmetry breaking.

(ii) Inflation and supersymmetry

The mass scale of inflation in the EFT is determined by the Hubble parameter H .

For consistency one needs $H < \Lambda_{QG}$

This translate into the following lower bound on the gravitino mass

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

For $n = 3$ $m_{3/2} > H$

[see also R. Kallosh, A. Linde (2004);
J. Conlon, R. Kallosh, A. Linde, F. Quevedo (2008);
F. Hasegawa, K. Mukaida, K. Nakayama, T. Terada, Y. Yamada (2017)]

Susy breaking scale must be higher than the scale of inflation!

CMB and the scalar-to-tensor ratio r :

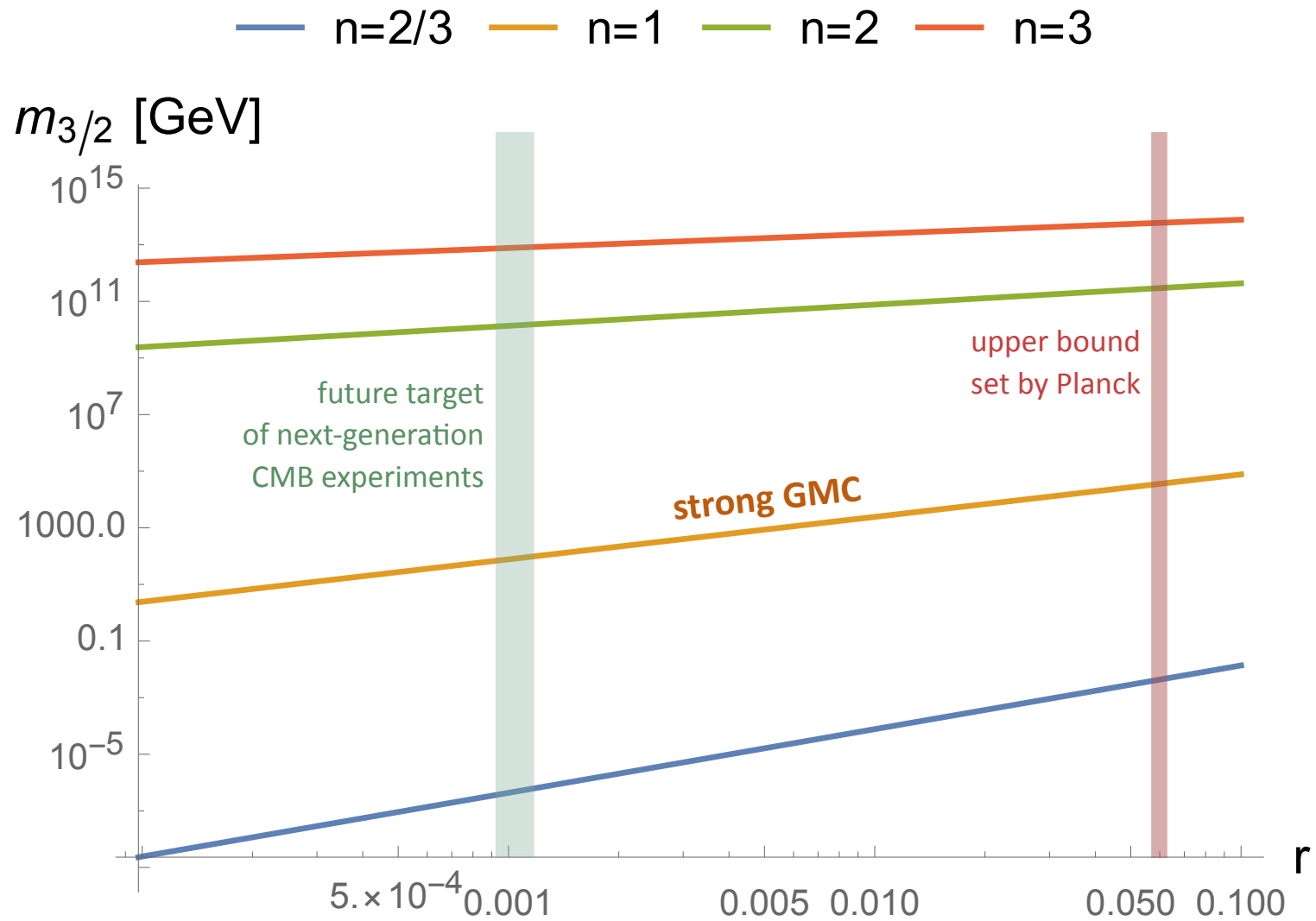
$$H = \sqrt{\frac{\pi^2 A_s r}{2}} M_P \simeq 10^{-4} \sqrt{r} M_P$$

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

Currently $r_{exp} \lesssim 0.06$

Next CMB experiments try to reach $r = \mathcal{O}(10^{-3})$

So one can reach $m_{3/2} \geq 10^2 \text{ GeV} \quad (n = 1)$



V) Outlook:

- There are various swampland conjectures, motivated from strings and black holes.

Many of them are related and hinting at a deeper common origin.

- Two specific swampland conjectures:

ADC: Λ_{AdS} is setting the cut-off of the theory.

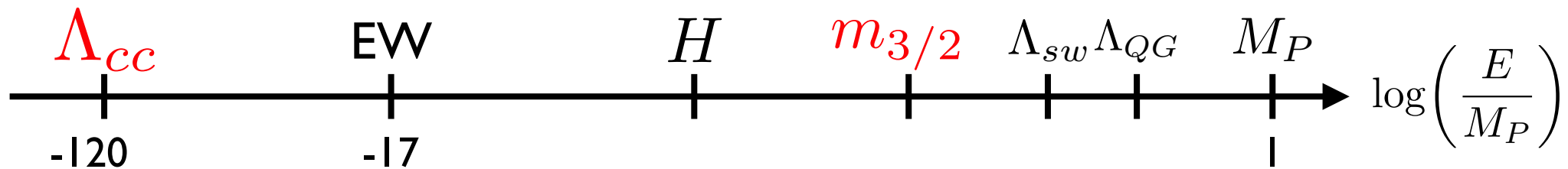
GMC: $m_{3/2}$ is setting the cut-off of the theory.

Perhaps there is parametric link of the form

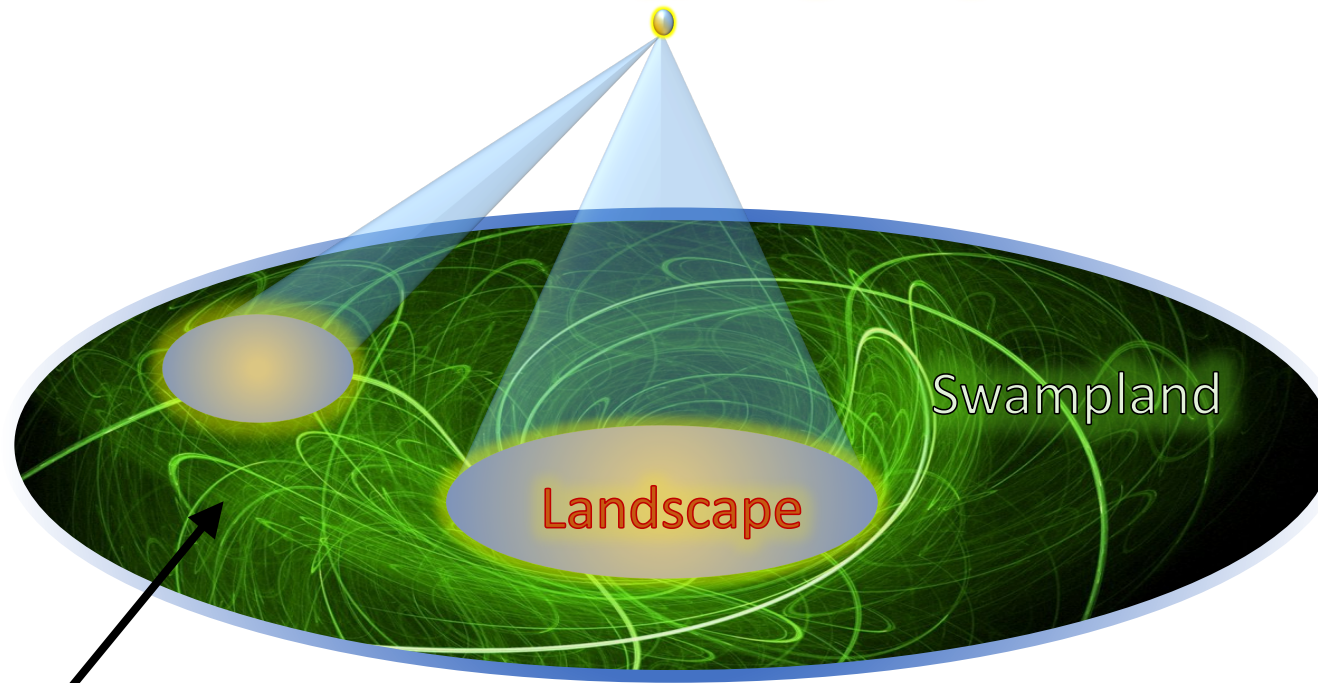
$$m_{3/2}^2 \sim |\Lambda|^p$$

Strong constraints from inflation on $m_{3/2}$

Susy breaking scale is of order or higher than the scale of inflation!



Quantum Gravity / String Theory



Low energy supersymmetry apparently belongs to the swampland !

Thank you !