Tegernsee
8/11/2021

The unbearable lightness of charged gravitinos

Gianguido Dall'Agata

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together with
N. Cribiori, M. Emelin, F. Farakos and M. Morittu

dS Landscape in Supergravity

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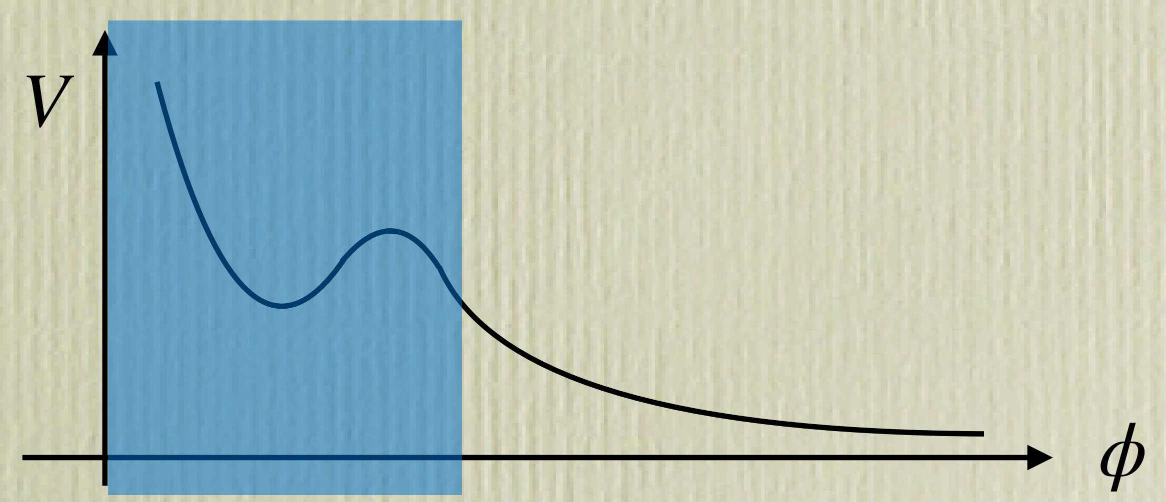
- **dS** *critical points of extended supergravities are* ***sparse at best*** Fre, Trigiante, Van Proeyen
- ***Uplifts*** *to String Theory only for models* ***without scale separation***
- ***Generic Dine–Seiberg problem***



- ***Swampland criteria*** *(de Sitter, Transplanckian Censorship,...)*

Our progress:

Cribiori, GD, Emelin, Farakos, Morittu

Swampland constraints

Magnetic-WGC constraints

Charact.: Gravitino mass,

gauge group,...

Use only ***supergravity***

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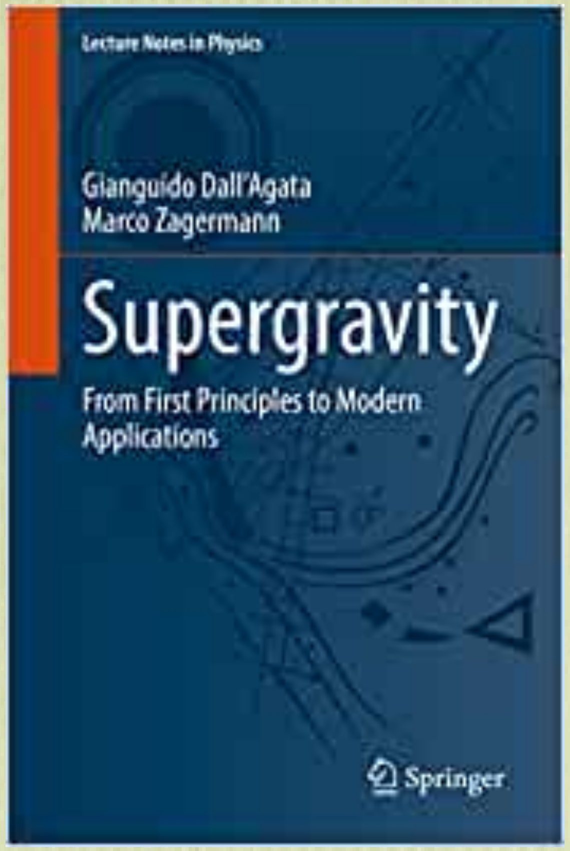


Looking for De Sitter

- *(meta)stable dS in N>1 very sparse*
- *Suggested ingredients:* Fre, Trigiante, Van Proeyen
  - ***Non compact gaugings***
  - ***de Roo–Wagemans symplectic angles***
  - ***Fayet–Iliopoulos terms***

- *(meta)stable dS in N>1 very sparse*
- *Suggested ingredients:*
  - ***Non compact gaugings***
  - ***Smart choice of symplectic frame***
  - ***Fayet–Iliopoulos terms***

- *(meta)stable dS in N>1 very sparse*
- *Either:*
  - ***Non compact gaugings***
- *or:*
  - ***Fayet–Iliopoulos terms***

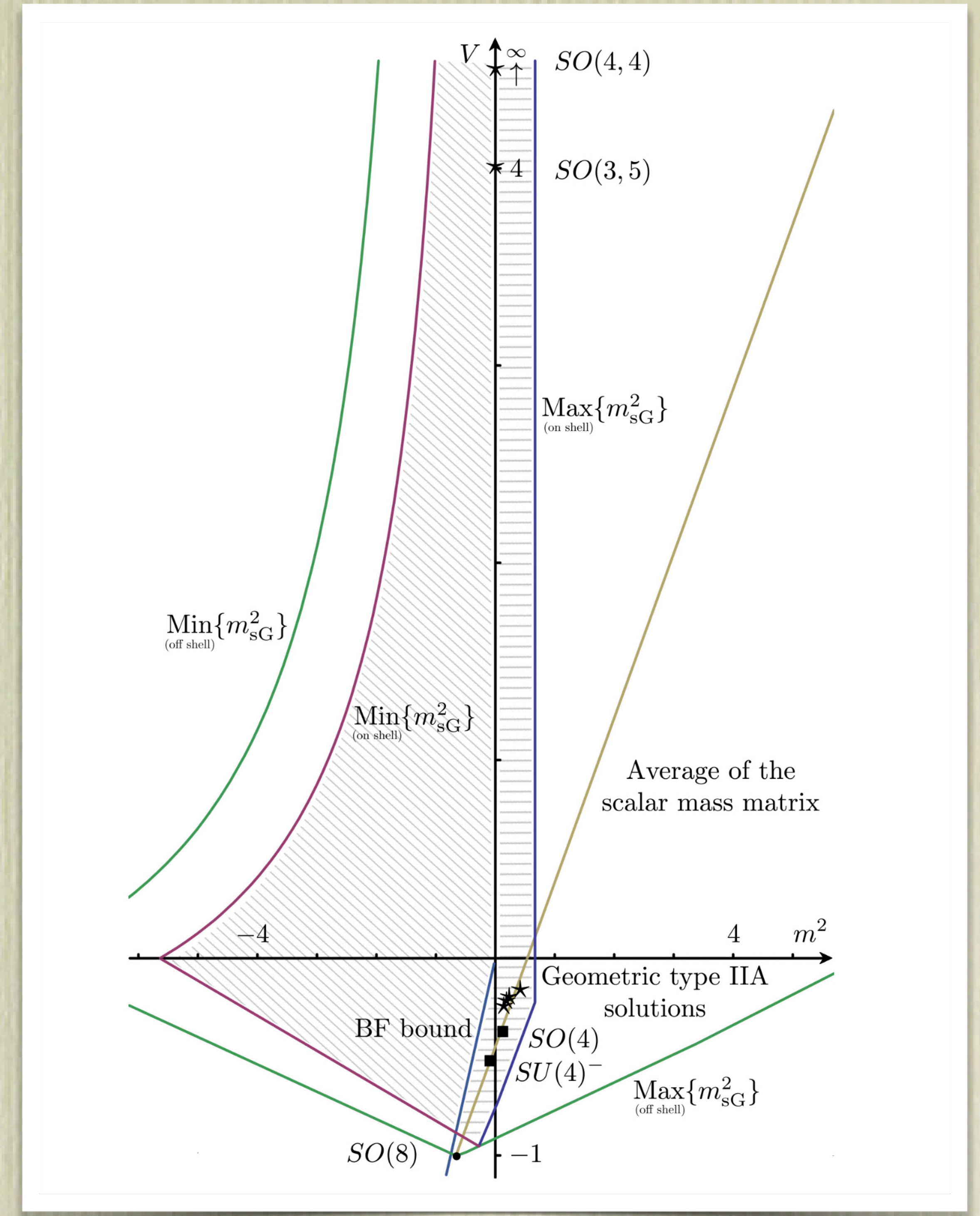
- *Attempts at **no go** failed*

  N=8: BORGHESE, LINARES, ROEST
  N=2: GOMEZ-REINO, LOUIS, SCRUCCA; CATINO, SCRUCCA

- *N=8 example of* ***marginally unstable*** *de Sitter in* $SO(4,4)_\omega$

  GD, INVERSO

BORGHESE, LINARES, ROEST 1112.3939



Weak Gravity vs. De Sitter

- **Swampland** conjectures **challenge** the survival of supergravity de Sitter vacua

- *dS conjecture* OOGURI, PALTI, SHIU, VAFA

$$|\nabla V| \geq \frac{c}{M_P} V \qquad \text{or} \qquad \min\left(\nabla_i \nabla_j V \right) \leq -\frac{c'}{M_P^2} V$$

- Surviving critical points challenged by other swampland conjectures
(TPCC, SSWGC, Festina-Lente, ***Magnetic-WGC***)

Gravity + U(1)

CRIBIORI, GD, FARAKOS

$$e^{-1}\mathscr{L} = \frac{1}{2} M_P^2 R - \frac{1}{4g^2} F_{mn}F^{mn} - 3H^2 M_P^2 + \dots \ ,$$

+ *charged matter* $\partial_m \chi + i\, q\, A_m\, \chi \ , \qquad q \in \mathbb{Z}$

as **effective theory**

$$e^{-1}\mathscr{L}_{grav.} = M_P^2 \left(\frac{1}{2} R + \frac{\alpha}{\Lambda_{\mathrm{UV}}^2} R^2 + \cdots \right)$$

On de Sitter $R = 12H^2 \gg R^2/\Lambda_{UV}^2$

Consistency: $\quad H \ll \Lambda_{UV}$

Gravity + U(1) Cribiori,GD,Farakos

$$e^{-1}\mathscr{L} = \frac{1}{2}M_P^2 R - \frac{1}{4g^2}F_{mn}F^{mn} - 3H^2M_P^2 + \dots ,$$

+ *charged matter* $\partial_m\chi + i\,q\,A_m\,\chi\ ,\qquad q \in \mathbb{Z}$

as **effective theory** on de Sitter

$$\frac{1}{\Lambda_{UV}} \sim \lambda_{UV} \ll \lambda_{EFT} \lesssim \frac{1}{H}$$

Consistency: $H \ll \Lambda_{UV}$

Magnetic WGC: The cutoff scale Λ_{UV} of the effective theory is bounded by the gauge coupling

$$\Lambda_{UV} \lesssim g\, M_P$$

Arkani-Hamed, Motl, Nicolis, Vafa; Huang, Li, Song; Antoniadis, Benakli

Consistency bound:

$$H \ll g\, M_P$$

Cribiori, GD, Farakos

What we find:

- ***large classes have*** $H \sim g\, q_{3/2}\, M_P$
- ***Parametrically light gravitini in the Swampland***

- *Example: de Sitter in N=2 general matter coupled sugra*
  - Scalar geometry = ***Special–Kähler*** (vectors) + ***Quaternionic–Kähler*** (hypers)
  - Encoded in
    - *Projective holomorphic coordinates* $X^{\Lambda}(z)$ and *sections* $Z = \left(X^{\Lambda}, F_{\Lambda}\right)$
    - Kähler potential: $K = -\log\, i\left(\bar{X}^{\Lambda} F_{\Lambda} - X^{\Lambda} \bar{F}_{\Lambda}\right)$
    - *Covariantly holomorphic symplectic sections* $V = \left(L^{\Lambda}, M_{\Lambda}\right) \equiv e^{K/2}\, \left(X^{\Lambda}, F_{\Lambda}\right)$

GD, Emelin, Farakos, Morittu

- *Example: de Sitter in N=2 general matter coupled sugra*
  - Scalar geometry = ***Special–Kähler*** (vectors) + ***Quaternionic–Kähler*** (hypers)
  - Encoded in
  - *Sections* $V = \left(L^\Lambda, M_\Lambda\right) \equiv e^{K/2}\,\left(X^\Lambda, F_\Lambda\right)$
  - Kähler potential: $K = -\log\, i\left(\overline{X}^\Lambda F_\Lambda - X^\Lambda \overline{F}_\Lambda\right)$
  - *Vector* and *hyper isometries*: $k^I_\Lambda(z)$ $k^u_\Lambda(q)$
  - and ***prepotentials***: $P^0_\Lambda(z,\bar{z})$, $P^x_\Lambda(z,\bar{z})$, $x = 1,2,3.$

GD, Emelin, Farakos, Morittu

- *Example: de Sitter in N=2 general matter coupled sugra*
  - Potential from (*electric*) gauging:

$$\mathscr{V} = \mathscr{V}_{D_1} + \mathscr{V}_{D_2} + \mathscr{V}_F$$

$$\mathscr{V}_{D_1} = |\overline{L}^\Lambda k^I_\Lambda|^2 = |D_I L^\Lambda P^0_\Lambda|^2$$

Non. Abelian vector gauging

$$\mathscr{V}_{D_2} = 4|\overline{L}^\Lambda k^u_\Lambda|^2$$

Hyper gauging

$$\mathscr{V}_F = \left(g^{I\bar{J}} D_I L^\Lambda \overline{D}_{\bar{J}} \overline{L}^\Sigma - 3\, L^\Lambda \overline{L}^\Sigma\right) P^x_\Lambda P^x_\Sigma$$

Hyper gauging + Fayet–Iliopoulos terms

  - **Gravitino mass matrix**: $m_{3/2\,ij} = i\, L^\Lambda P^x_\Lambda\, (\sigma^x)_{ij}$

- Example: Abelian gaugings in N=2 CRIBIORI,GD,FARAKOS
  - *N=2 sugra + vectors +* $\mathrm{U}(1)_R$ *FI* $\quad P^x_\Lambda = e_\Lambda \delta^x_3$
  - *Scalar Potential*

$$\mathscr{V} = e^K\left(g^{I\bar{J}} D_I W \overline{D}_{\bar{J}} \overline{W} - 3W\overline{W}\right) \qquad D_I W = W_I + K_I W$$

$$W = \langle Q, Z\rangle = X^\Lambda e_\Lambda - F_\Lambda m^\Lambda$$

- *Unstable critical points, compatible with dS conj.*

$$\partial^J \partial_I \mathscr{V}\, D_J W = -\,2\mathscr{V}\, D_I W$$

FRE, TRIGIANTE, VAN PROEYEN

Cribiori,GD,Farakos

- *Non-minimal couplings,* $m_{3/2} = |X^\Lambda P^x_\Lambda| = 0,\ m^\Lambda = 0$

$$e^{-1}\mathscr{L}_{kin.} = \frac{1}{4}\,\mathscr{I}_{\Lambda\Sigma}F^\Lambda_{mn}F^{\Sigma mn} \qquad V|_* = -\frac{1}{2}\,\mathscr{I}^{\Lambda\Sigma}e_\Lambda e_\Sigma > 0$$

$$D_m\psi_{nA} = \ldots + \frac{i}{2}\,A^\Lambda_m e_\Lambda (\sigma^3)_A{}^B\psi_{nB}$$

- Gauge vector $v_m = \Theta_\Lambda A^\Lambda \qquad \Theta_\Lambda = e_\Lambda/(2q)$

- *Canonical kin. Term*

$$e^{-1}\mathscr{L}_{kin.} = \frac{1}{4}\,\frac{2q^2}{\mathscr{V}}\,F_{mn}(v)F^{mn}(v) + \ldots$$

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$$e^{-1}\mathscr{L}_{kin.} = \frac{1}{4}\,\frac{2q^2}{\mathscr{V}}\,F_{mn}(v)F^{mn}(v) + \ldots$$

$$\mathscr{V} = 2\,g^2\,q^2$$

In the swampland!!

- *Example: de Sitter in N=2 general matter coupled sugra*
  - When $m_{3/2\,ij} = i\, L^\Lambda P^x_\Lambda\, (\sigma^x)_{ij} = 0$, the potential simplifies drastically:

$$\mathcal{V} = \mathcal{V}_{D_1} + \mathcal{V}_{D_2} + \mathcal{V}_F$$

$$\mathcal{V}_{D_1} = |\overline{L}^\Lambda k^I_\Lambda|^2 = |D_I L^\Lambda P^0_\Lambda|^2$$

$$\mathcal{V}_{D_2} = 4\,|\overline{L}^\Lambda k^u_\Lambda|^2$$

$$\mathcal{V}_F = \left(g^{I\bar{J}} D_I L^\Lambda \overline{D}_{\bar{J}} \overline{L}^\Sigma - 3\, L^\Lambda \overline{L}^\Sigma\right) P^x_\Lambda P^x_\Sigma$$

GD,Emelin,Farakos, Morittu

- *Example: de Sitter in N=2 general matter coupled sugra*
  - When $m_{3/2\,ij} = i\,L^\Lambda P^x_\Lambda\,(\sigma^x)_{ij} = 0,$

$$\mathscr{V} = \mathrm{Tr}\left(Q^2\right) + 4\left|\overline{L}^\Lambda k^u_\Lambda\right|^2$$

  - where Q is the *charge matrix* of the gravitini

$$e^{-1}\mathscr{L}_{kin.\,3/2} = -\,\overline{\psi}^i_m\gamma^{mnr}D_n(\omega)\psi_{ir} - i\,\overline{\psi}^i_m\gamma^{mnr}\,A^A_n\,Q_{A\,i}{}^j\,\psi_{jr}\,,$$

$$Q_{A\,i}{}^j = \frac{1}{2}\left(\delta^j_i P^0_A + \sigma^x{}_i{}^j P^x_A\right)$$

Canonically normalized gauge vectors

GD,Emelin,Farakos, Morittu

- *Example: de Sitter in N=2 general matter coupled sugra*
  - If ψ^i_m are ***charged*** under a U(1) with charge q:

$$\mathscr{V} = \mathrm{Tr}\left(Q^2\right) + 4\left|\overline{L}^\Lambda k^u_\Lambda\right|^2 \geq q^2$$

  - And since $H^2 = \mathscr{V}/3$,

$$H = \sqrt{\frac{\mathscr{V}}{3}} \geq \frac{q}{\sqrt{3}} \simeq \frac{\Lambda_{UV}}{\sqrt{3}}$$

GD, EMELIN, FARAKOS, MORITTU

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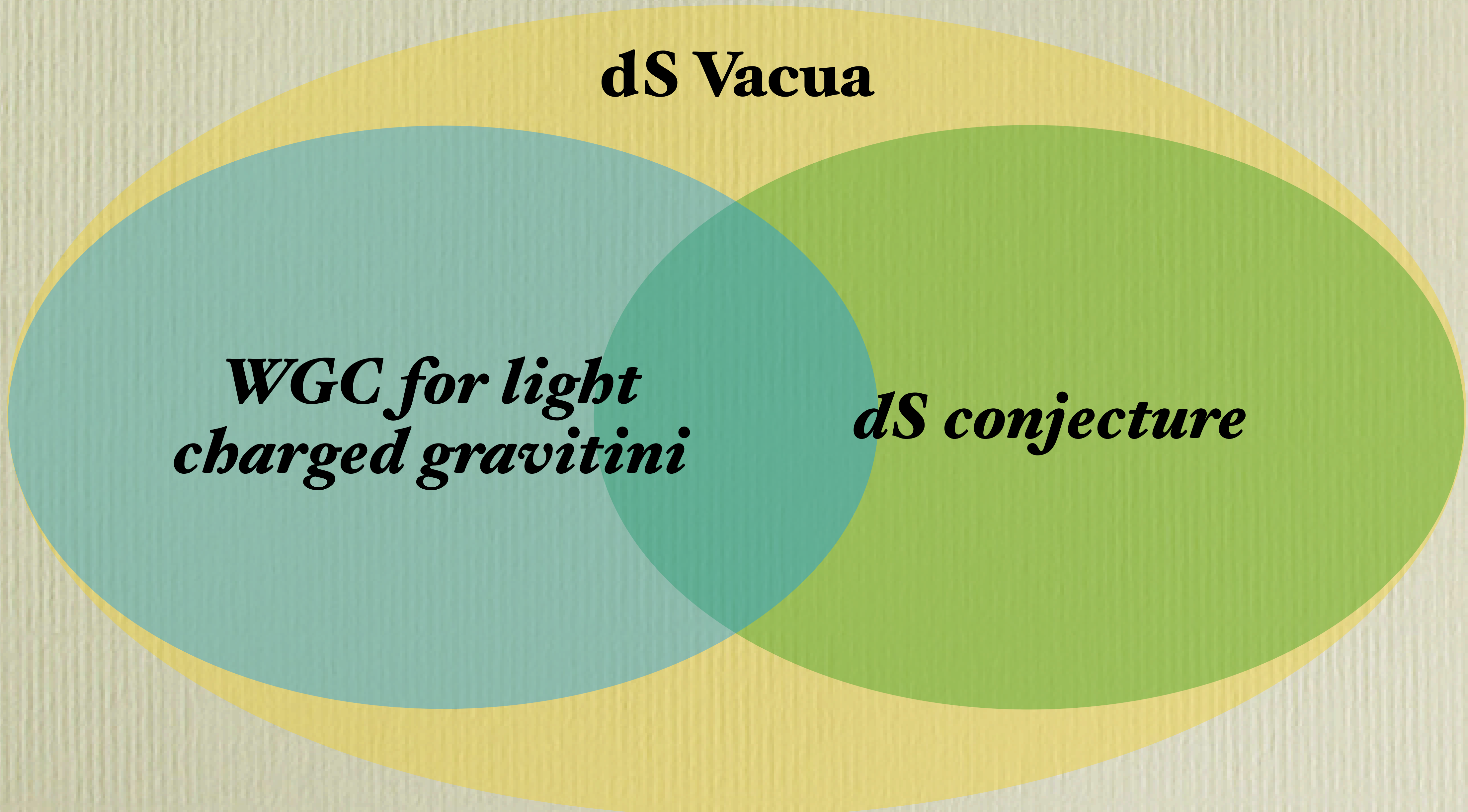
In the swampland!

GD, EMELIN, FARAKOS, MORITTU

- ***General result:***
  - ***Massless charged gravitini*** *w.r.t.* ***Abelian*** *residual gauge groups in gauged sugra put* ***ANY*** *de Sitter critical point in the swampland*
    - *Direct proofs:* N=1 D-terms, N=2, N=8
    - *WGC enough* (no need of dS conjectures)
    - Large variety of examples of models within this class
    - Proof of existence of models outside

GD,Emelin,Farakos,
Morittu



GD, Emelin, Farakos, Morittu

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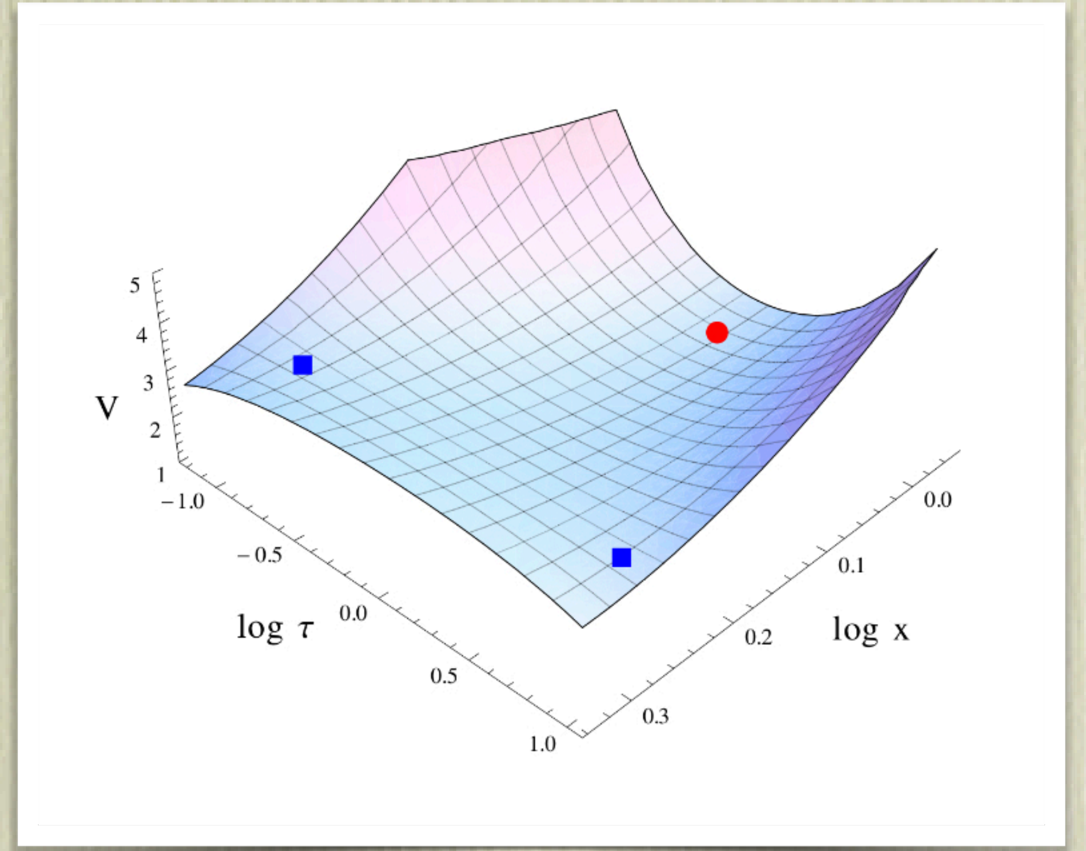
$N = 8$

$SO(4,4)_\omega$

GD-Inverso



GD, Emelin, Farakos, Morittu

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$$m_{3/2} = 0 \qquad \left|\frac{V''}{V}\right| = 2$$

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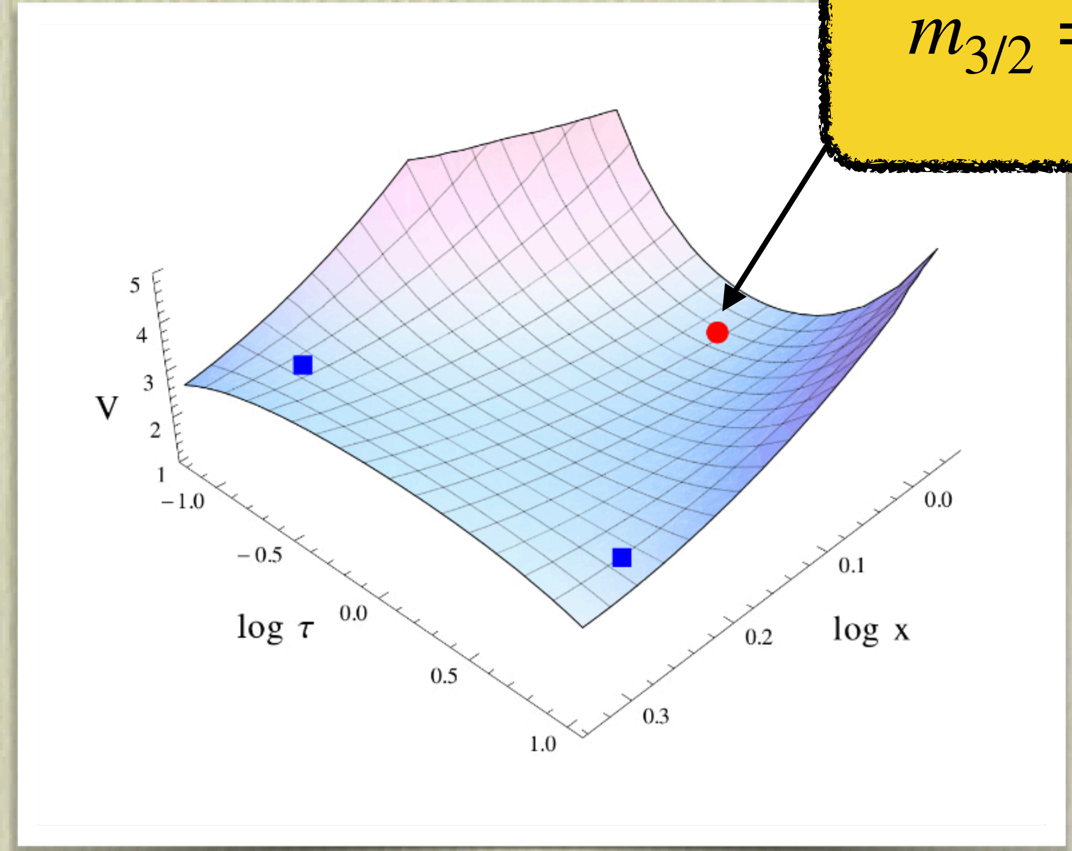

GD,Emelin,Farakos, Morittu

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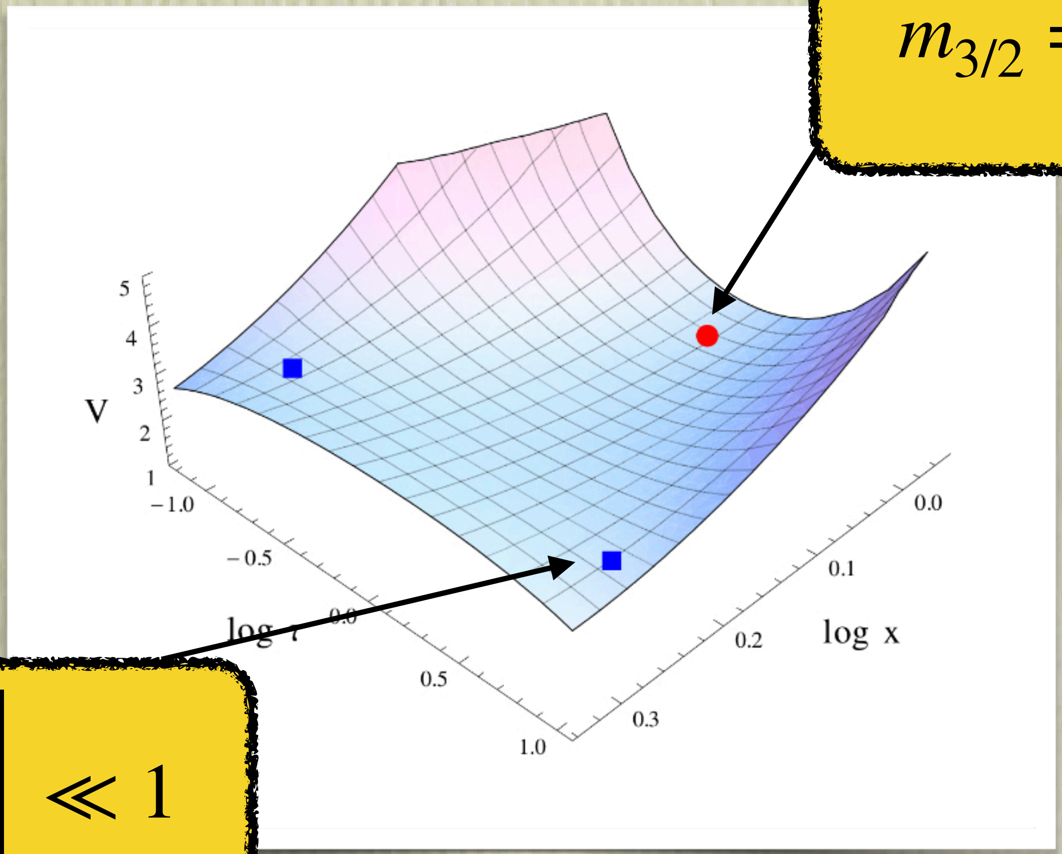

$$m_{3/2} \neq 0 \qquad \left|\frac{V''}{V}\right| \ll 1$$

GD, Emelin, Farakos, Morittu

- ***Generalization:***
  - *Non-Abelian residual gauge groups*
  - Parametrically light gravitino masses

Model with G = SO(3) × O(1,1) $\mathscr{V} = 2\,e_0^2 + 3\,e_1^2$

dS vacuum w/ *modulus z*

and G_{res} = U(1) [enh. SO(3)] $\Lambda_{UV} = e_1 \sqrt{\dfrac{1+z^2}{1-z^2}}$

variable $m_{3/2} = e_1 \dfrac{z}{\sqrt{1-z^2}}$

GD,Emelin,Farakos, Morittu

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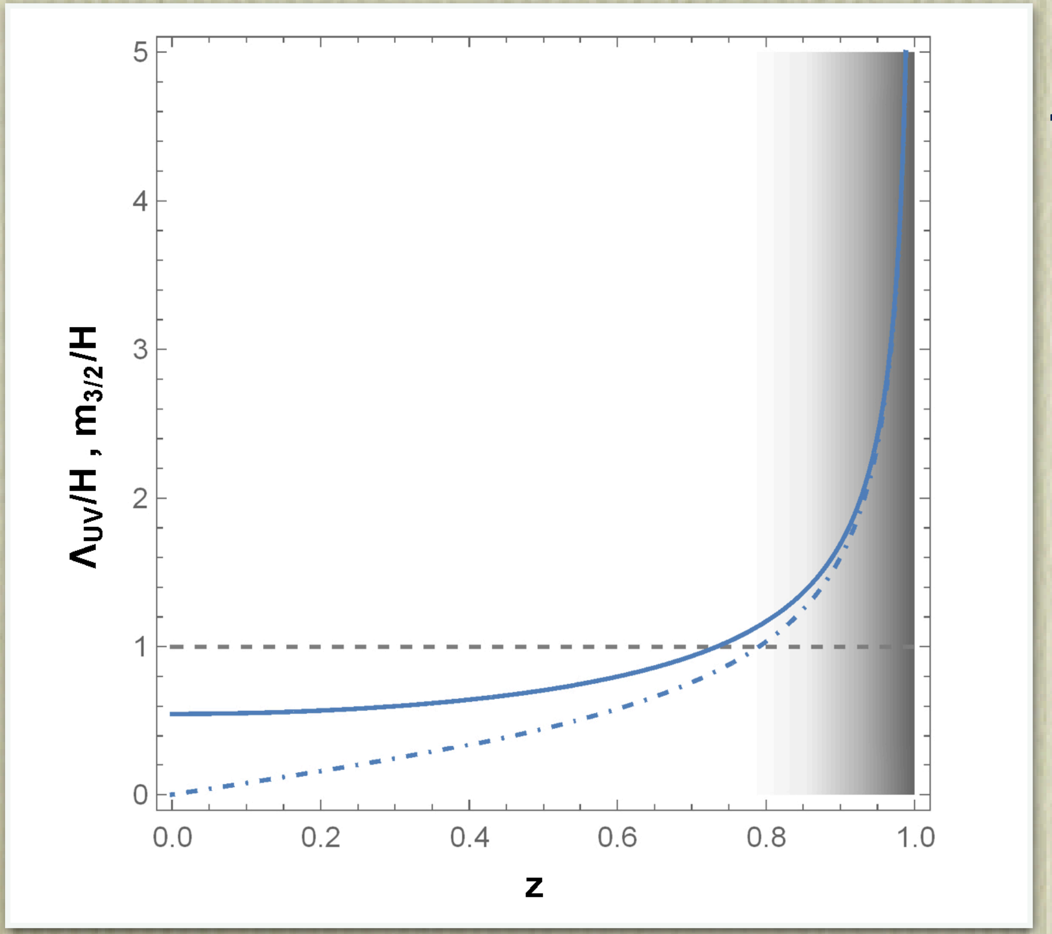
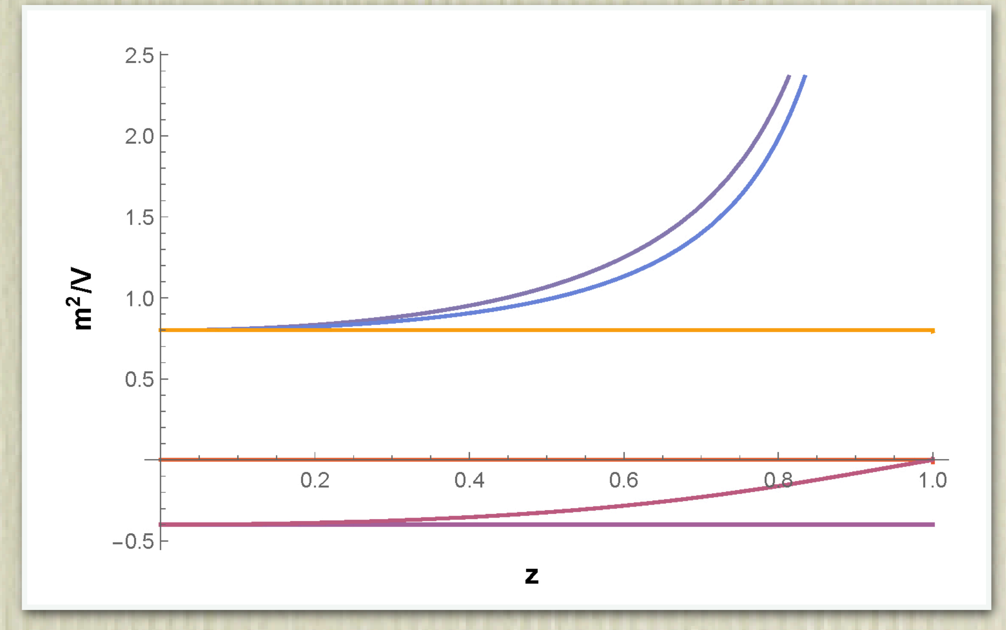


Cutoff and gravitini

Scalar masses



Summarizing:

de Sitter landscape in supergravity is sparse

Characterization still uncertain

Swampland conjectures kills most supergravity models

Parametrically light charged gravitini are in the swampland