Non-SUSY String vacua & Exceptional Field Theory

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Rencontres Theoriciens Paris Seminar
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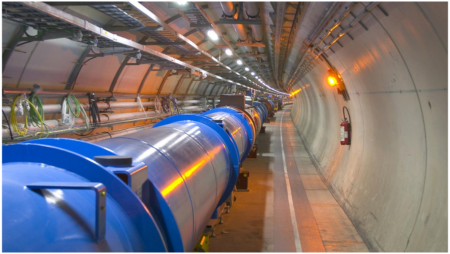
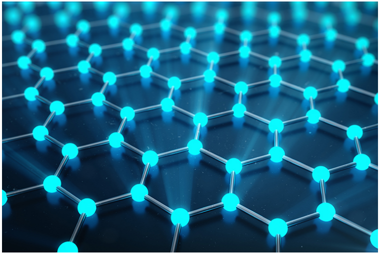
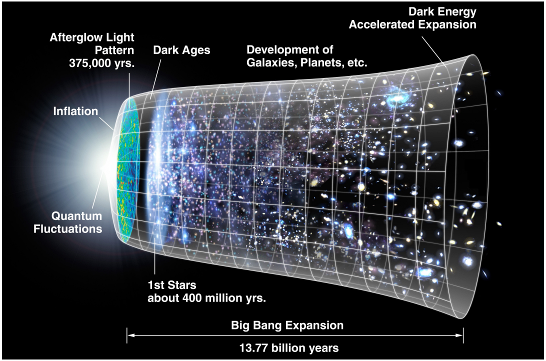
with Samtleben & Giambrone, Guarino, Nicolai, Sterckx, Trigiante

Quest for non-SUSY vacua







Problems

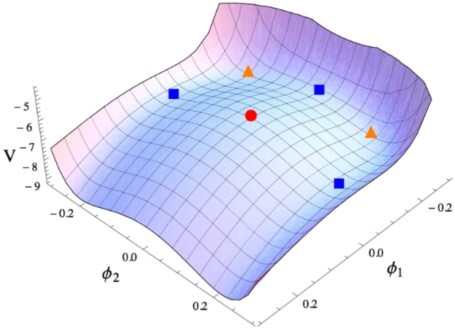
Construct & study physically relevant solutions

- Solve second-order PDEs
- Fluctuations
- Instabilities

Lower-dimensional models

Useful: lower-dimensional model

- Finite number of fields $\rightarrow$ easier solutions
- Study fluctuations $\rightarrow$ stability
- Captures only part of physics



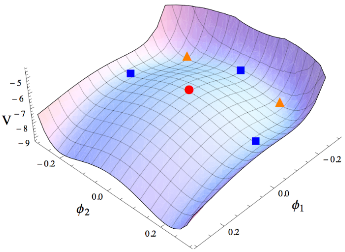
Non-SUSY AdS vacua

AdS $\times M_{\text{compact}}$

- No scale separation $\rightarrow$ no effective theory
- "Consistent truncation" instead
- All solutions of lower-d theory $\rightarrow$ solutions of full higher-d theory
- Difficult to construct

Lower-dimensional models vs string theory

Easier to construct solutions & study subset of fluctuations



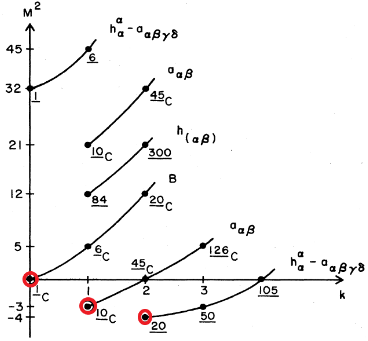


FIG. 2. Mass spectrum of scalars.

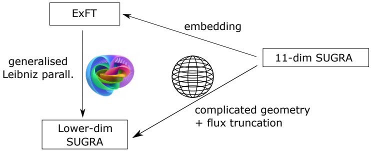
- Most non-SUSY AdS solutions already unstable! c.f. [Comsa, Firsching, Fischbacher '19], [Bobev, Fischbacher, Gautason, Pilch '20]
- Is "zero-mode" stability enough?

Two goals:

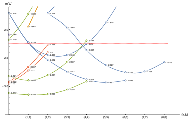
Uplift lower-dim gauged supergravity to string theory?

Full spectrum of masses $\Leftrightarrow$ perturbative stability in 10-/11-d?

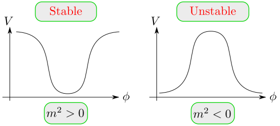
Exceptional Field Theory
& consistent truncations



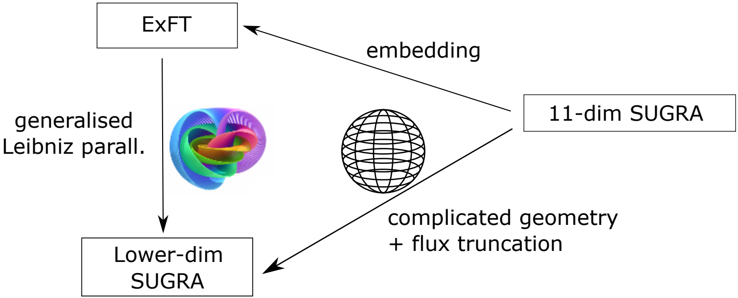
Kaluza-Klein spectroscopy



Stability of non-SUSY AdS_4



Exceptional field theory & consistent truncations



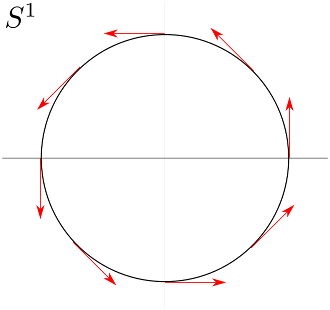
Consistent truncation

Non-linear embedding of lower-dimensional
supergravity into 10-/11-d supergravity

- All solutions of lower-d SUGRA $\rightarrow$ solutions of 10-/11-d SUGRA
- Non-linearity: highly non-trivial!
- Symmetry arguments crucial for consistency & construction

Consistent truncation on group manifold

Symmetry arguments crucial for consistency, e.g. group manifold



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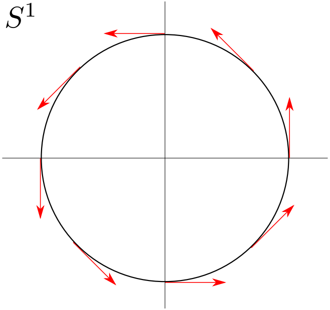


$$U_m{}^\mu \in \mathrm{GL}(D)$$

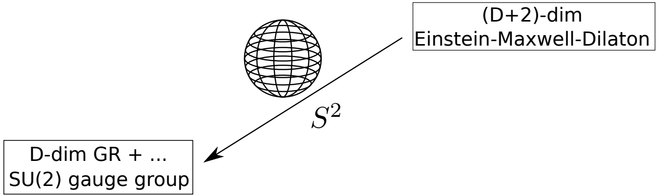
$$L_{U_m} U_n = f_{mn}{}^p U_p$$

$$g_{\mu\nu}(x, y) = g_{mn}(x)\,(U^{-1})_\mu{}^m(y)(U^{-1})_\nu{}^n(y)$$

Larger symmetry groups from generalising geometry

Symmetry argument for other consistent truncations?

$$S = \int d^{D+2}x\,\sqrt{|g|}\left(R_g - (\nabla\phi)^2 - e^{\alpha\phi}F^2\right)$$



$$ds^2_{D+2} = Y^{\frac{1}{D}}\left(\Delta^{\frac{1}{D}}ds^2_D + g^{-2}\Delta^{-\frac{D-1}{D}}T^{-1}_{ij}\mathfrak{D}\mu^i\mathfrak{D}\mu^j\right),$$

$$e^{\sqrt{\frac{2(D)}{D+1}}\hat{\phi}} = \Delta^{-1}Y^{\frac{D-1}{D+1}},$$

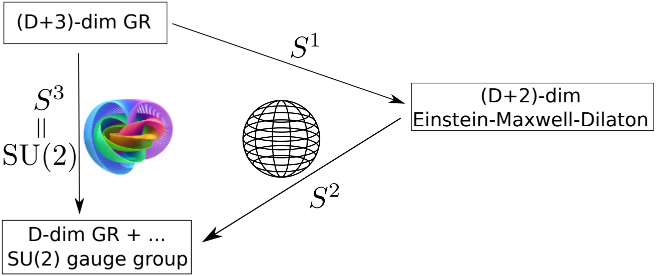
$$\hat{F}_2 = \frac{1}{2}\epsilon_{ijk}\left(g^{-1}\Delta^{-2}\mu^i\mathfrak{D}\mu^j\wedge\mathfrak{D}\mu^k - 2g^{-1}\Delta^{-2}\mathfrak{D}\mu^i\wedge\mathfrak{D}T_{jl}T_{km}\mu^l\mu^m - \Delta^{-1}F^{ij}_{(2)}T_{kl}\mu^l\right).$$

[Cvetic, Lü, Pope '00]

Larger symmetry groups from generalising geometry

Symmetry argument for other consistent truncations?

$$S = \int d^{D+3}x \sqrt{|G|}\,(R_G)$$



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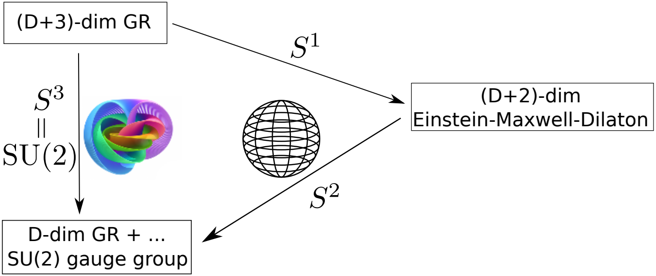

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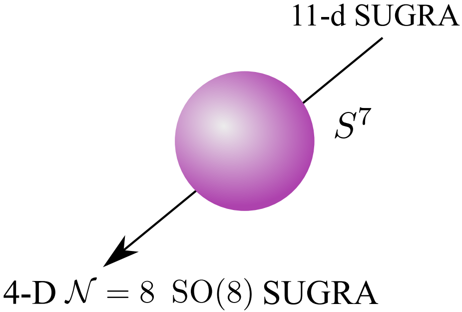
$$g_{\mu\nu}(x, y) = g_{mn}(x) \, (U^{-1})_{\mu}{}^{m}(y) (U^{-1})_{\nu}{}^{n}(y)$$

[Cvetic, Lü, Pope, Gibbons '03]

Consistent truncations beyond group manifolds

Consistent truncations of 10-d/11-d SUGRA beyond group manifolds?



[de Wit, Nicolai '82]

Exceptional Field Theory

[Berman, Perry '10], [Coimbra, Strickland-Constable, Waldram '11], [Hohm, Samtleben, '13], ...

Exceptional Field Theory: Unify metric + fluxes of supergravity

IIB supergravity on $M_4 \times C_6$:

$$\{g\,,\ \Phi\,,\ B_{(2)}\,,\ A_{(0)}\,,\ A_{(2)}\,,\ A_{(4)}\,,\ldots\} = \mathcal{M}_{MN} \in \frac{E_{7(7)}}{\mathrm{SU}(8)}\,.$$

Diffeo + gauge transf $\rightarrow$ generalised vector field $V^M \in \mathbf{56}$ of $E_{7(7)}$
Lie derivative $\rightarrow$ generalised Lie derivative

$$\mathcal{L}_V = V^M \partial_M - (\partial \times_{adj} V) = \text{diffeo} + \text{gauge transf}\,,$$

with $\partial_M = \left(\partial_i\,,\ \partial^i\,,\ \partial^{ijk}\,,\ \ldots\right) = (\partial_i\,,\ 0\,,\ \ldots\,,\ 0)$.

Exceptional Field Theory = reformulation of supergravity

Exceptional Field Theory: Reformulation of IIB supergravity

$$\{g\,,\ \Phi\,,\ B_{(2)}\,,\ A_{(0)}\,,\ A_{(2)}\,,\ A_{(4)}\,,\ldots\} = \mathcal{M}_{MN}$$

$$L = e^{-2\Phi}\left(R - \frac{1}{12}H_{\mu\nu\lambda}H^{\mu\nu\lambda} + 4\partial_\mu\Phi\partial^\mu\Phi\right) + \ldots$$

with $H_{\mu\nu\rho} = 3\partial_{[\mu}B_{\nu\rho]}$.

Exceptional Field Theory = reformulation of supergravity

Exceptional Field Theory: Reformulation of IIB supergravity

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$$\begin{aligned} L &= e^{-2\Phi}\left(R - \frac{1}{12}H_{\mu\nu\lambda}H^{\mu\nu\lambda} + 4\partial_\mu\Phi\partial^\mu\Phi\right) + \dots \\ &= \mathcal{M}^{MN}\partial_M\mathcal{M}^{PQ}\partial_N\mathcal{M}_{PQ} + \dots \end{aligned}$$

Exceptional Field Theory = reformulation of supergravity

Exceptional Field Theory: Reformulation of IIB supergravity

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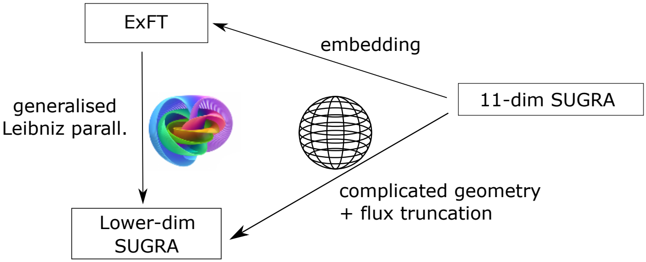
Generalised Lie derivative $\Rightarrow$ generalised Ricci scalar

Exceptional Field Theory and consistent truncations

Consistent truncations captured by
"generalised group manifolds" in ExFT



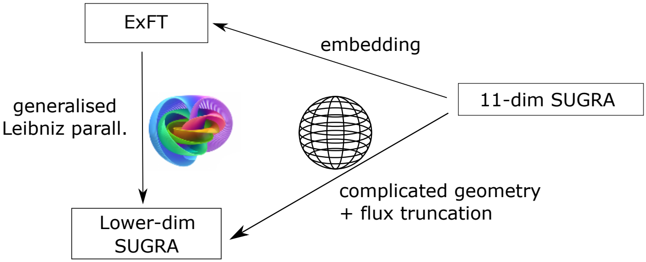
$$U_A{}^M \in E_{7(7)}$$

$$\mathcal{L}_{U_A} U_B = X_{AB}{}^C U_C$$

$$\mathcal{M}_{MN}(x, Y) = M_{AB}(x)(U^{-1})_M{}^A(Y)(U^{-1})_N{}^B(Y)$$

Exceptional Field Theory and consistent truncations

Consistent truncations captured by
"generalised Leibniz parallelisable manifolds" in ExFT



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Uplifting to string theory

Consistent truncations on S^p, $H^{p,q}$, $S^p \times S^q$, ...

[Aldazabal, Berman, Geissbühler, Cassani, Graña, Hohm, Inverso, Lee, EM, Marqués, Petrini, Samtleben, Strickland-Constable, Thompson, Trigiante, Waldram, ...]

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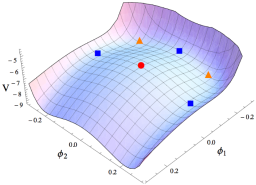

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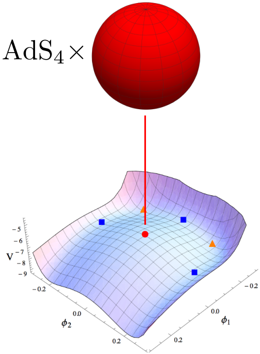

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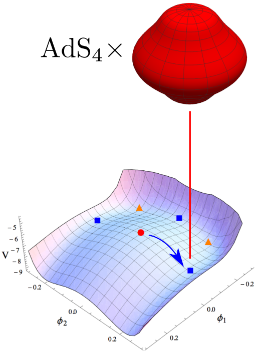

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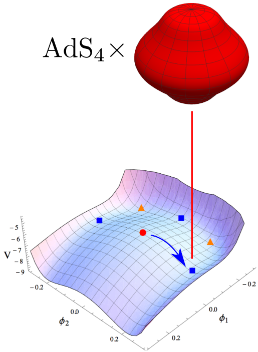
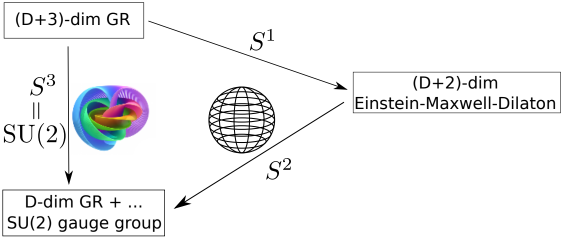


Multiplication by $E_{7(7)}$ matrix!

Higher-dimensional space?



Is there a similar higher-dimensional space underlying ExFT? General ∂_M?

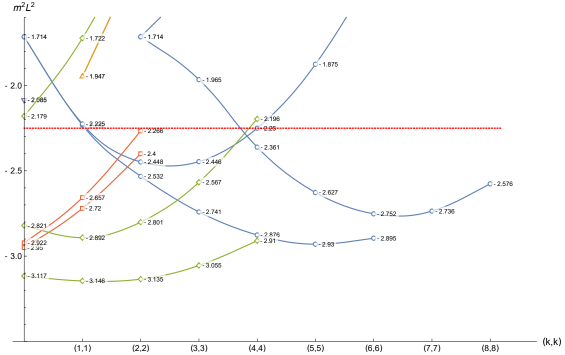
No!

Section condition:

$$\mathbb{P}_{MN}{}^{PQ}\partial_P \otimes \partial_Q = 0$$

Covariant restriction to 7 (11-d SUGRA) or 6 (IIB SUGRA) coordinates.

Kaluza-Klein spectroscopy



Kaluza-Klein spectroscopy

Consistent truncation:

- Lower-dimensional theory
- Compute subset of masses for any vacuum!

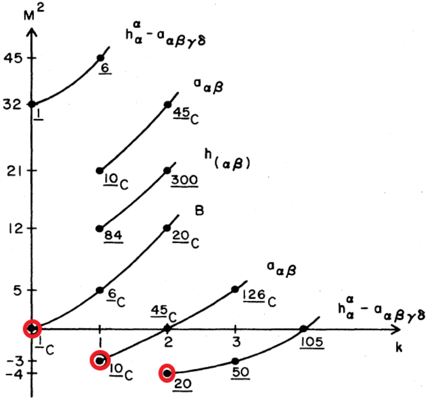
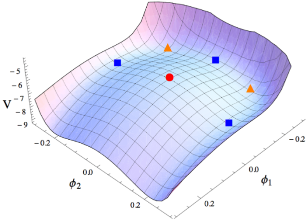


FIG. 2. Mass spectrum of scalars.



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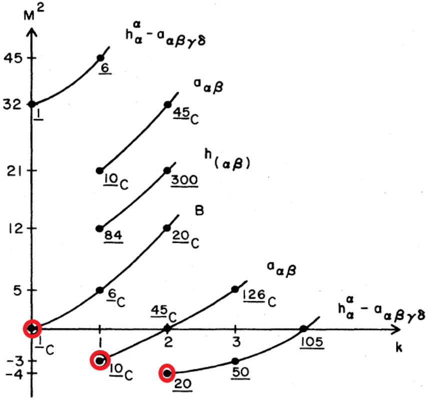

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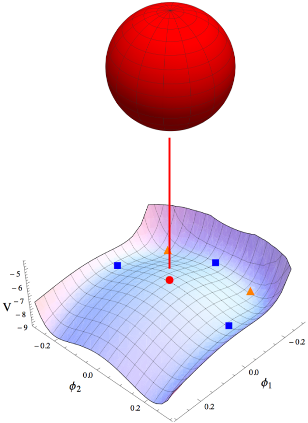

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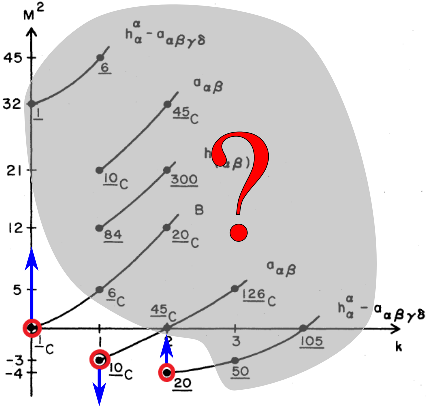

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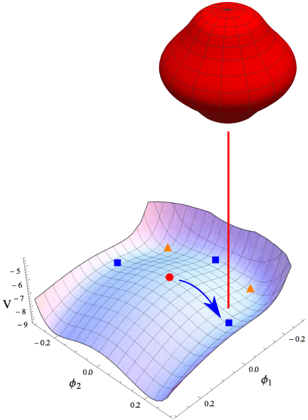

Kaluza-Klein spectroscopy

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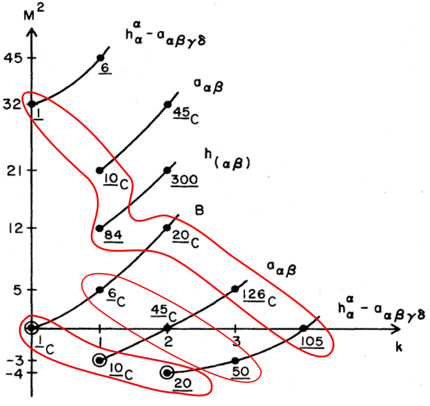
[EM, Samtleben PRL '20]
Extend this to full KK spectrum using ExFT!



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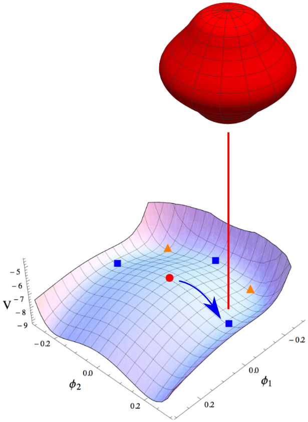

Traditional Kaluza-Klein spectroscopy

Traditionally:

- Spin-2 fields [Bachas, Estes '11] ✓
- $M_{int} = \frac{G}{H}$ ✓

Here: [EM, Samtleben PRL '20]

- Compactifications with few or no remaining (super-)symmetries!

Kaluza-Klein spectrum on $\mathrm{AdS}_D \times M_{compact}$

Free scalar on S^1:

$$0 = \partial_x^2 \phi(x, y) + \partial_y^2 \phi(x, y)\,,$$

$$\phi(x, y) = \phi^{(\ell)}(x)\, e^{i\,\ell\, y/R}\,, \qquad m^2 = \frac{\ell^2}{R^2}\,.$$

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E.g. IIB supergravity around $\text{AdS}_5 \times S^5$:

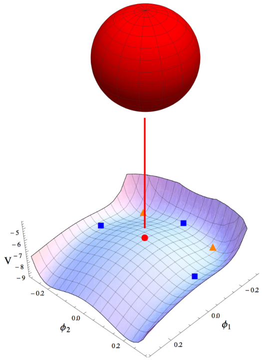
- Expand $h_{\mu\nu}$, Φ, χ, $B_{\mu\nu}$, $A_{\mu\nu}$, $A_{\mu\nu\rho\sigma}$, … in S^5 tensor harmonics
- Complicated mass diagonalisation, e.g.

$$\Delta_L h_{\mu\nu} = \frac{1}{3} F_{(\mu}{}^{\rho\sigma\kappa\lambda} f_{\nu)\rho\sigma\kappa\lambda} - \frac{1}{18} g_{\mu\nu} F_{\rho\sigma\kappa\lambda\tau} f^{\rho\sigma\kappa\lambda\tau} - F_{(\mu}{}^{\rho\sigma\kappa\tau} F_{\nu)}{}^{\delta}{}_{\sigma\kappa\tau} h_{\rho\delta}$$
$$- \frac{1}{36} h_{\mu\nu} F_{\rho\sigma\kappa\lambda\tau} F^{\rho\sigma\kappa\lambda\tau} + \frac{1}{9} g_{\mu\nu} F_{\rho\sigma\kappa\lambda\epsilon} F_{\tau}{}^{\sigma\kappa\lambda\epsilon} h^{\rho\tau}\,,$$

KK spectroscopy strategy

First at max symmetric point:

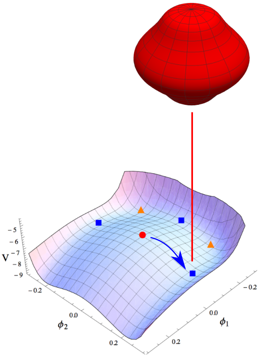
$$\mathcal{M}_{MN}(x, Y) = \delta_{AB}(U^{-1})_M{}^A(Y)(U^{-1})_N{}^B(Y)$$



KK spectroscopy strategy

Then at less symmetric point:

$$\mathcal{M}_{MN}(x, Y) = M_{AB}(x)(U^{-1})_M{}^A(Y)(U^{-1})_N{}^B(Y)$$



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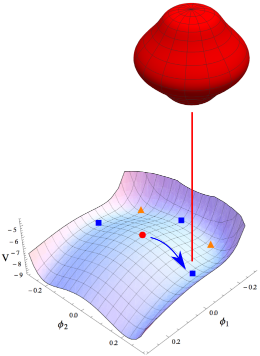
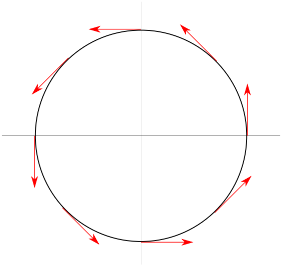


Multiplication by $E_{7(7)}$ matrix, $M_{AB}(x)$!

KK spectroscopy at max. symmetric point

${U_A}^M \in E_{7(7)}$ give basis for all fields



Only need scalar harmonics: $\mathcal{Y}_\Sigma$

c.f. $h_{ij}(x,y) = \sum_\ell h^{(\ell)}(x)\mathcal{Y}^{(\ell)}_{(ij)}(y), \quad b_{ij}(x,y) = \sum_\ell b^{(\ell)}(x)\mathcal{Y}^{(\ell)}_{[ij]}(y)$

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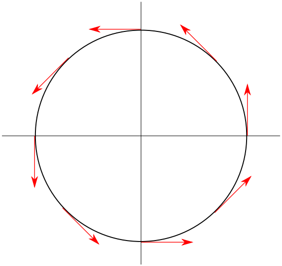

Only need scalar harmonics: $\mathcal{Y}_\Sigma$

$$\mathcal{M}_{MN}(x, Y) \in E_{7(7)}/\mathrm{SU}(8)$$

KK spectroscopy at max. symmetric point

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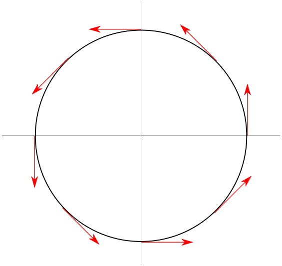


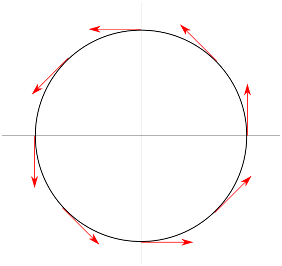
Only need scalar harmonics: $\mathcal{Y}_\Sigma$

$$\mathcal{M}_{MN}(x,Y) = (\delta_{AB} + {j_{AB}}^\Sigma(x)\mathcal{Y}_\Sigma)(U^{-1})_M{}^A(Y)(U^{-1})_N{}^B(Y)$$

$${j_{AB}}^\Sigma \in \mathfrak{e}_{7(7)} \ominus \mathfrak{su}(8)$$

KK spectroscopy at max. symmetric point

${U_A}^M \in E_{7(7)}$ give basis for all fields



Only need scalar harmonics: $\mathcal{Y}_\Sigma$

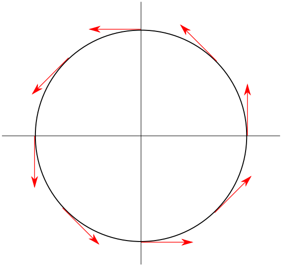
$$\mathcal{M}_{MN}(x, Y) = (\delta_{AB} + {j_{AB}}^{\Sigma}(x)\mathcal{Y}_\Sigma)(U^{-1})_M{}^A(Y)(U^{-1})_N{}^B(Y)$$

$${j_{AB}}^{\Sigma} \in \mathfrak{e}_{7(7)} \ominus \mathfrak{su}(8)$$

KK Ansatz = consistent truncation $\otimes$ scalar harmonics

KK spectroscopy at max. symmetric point

${U_A}^M \in E_{7(7)}$ give basis for all fields



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$${j_{AB}}^{\Sigma} \in \mathfrak{e}_{7(7)} \ominus \mathfrak{su}(8)$$

Immediate mass diagonalisation!

Mass matrix

- Lower-dim info:

$$\mathcal{L}_{U_A} U_B = X_{AB}{}^C U_C \,,$$

- Higher-dim info:

$$\mathcal{L}_{U_A} \mathcal{Y}_\Sigma = L_{K_A} \mathcal{Y}_\Sigma = \mathcal{T}_{A\,\Sigma}{}^{\Omega} \mathcal{Y}_\Omega \,.$$

Mass matrix:

$$\mathbb{M}^{(\text{scalar})}_{I\Sigma,J\Omega} = \mathbb{M}^{(0)}_{IJ}\,\delta_{\Sigma\Omega} + \delta_{IJ}\,\mathbb{M}^{(\text{spin}-2)}_{\Sigma\Omega} + \mathcal{N}_{IJ}{}^{C}\mathcal{T}_{C,\Omega\Sigma}$$

Mass matrix

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$$\mathcal{L}_{U_A} U_B = X_{AB}{}^C U_C \,,$$

- Higher-dim info:

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- Lower-dim SUGRA mass matrix $\mathbb{M}^{(0)}_{IJ}$

Mass matrix

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$$\mathcal{L}_{U_A} U_B = X_{AB}{}^C U_C \,,$$

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Mass matrix:

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- Lower-dim SUGRA mass matrix $\mathbb{M}^{(0)}_{IJ}$

$$\begin{aligned}\mathbb{M}^{(0)}_{IJ} = \frac{1}{7}\left(X_{AE}{}^F X_{BE}{}^F + X_{EA}{}^F X_{EB}{}^F + X_{EF}{}^A X_{EF}{}^B + 7\,X_{AE}{}^F X_{BF}{}^E\right) \mathcal{P}_{AD}{}^I \mathcal{P}_{BD}{}^J \\ + \frac{2}{7}\left(X_{AC}{}^E X_{BD}{}^E - X_{AE}{}^C X_{BE}{}^D - X_{EA}{}^C X_{EB}{}^D\right) \mathcal{P}_{AB}{}^I \mathcal{P}_{CD}{}^J \\ + \frac{1}{6}\,\mathcal{P}_{AB}{}^I \mathcal{P}_{CD}{}^J X_{FA}{}^B X_{FC}{}^D \,.\end{aligned}$$

Mass matrix

- Lower-dim info:
$$\mathcal{L}_{U_A} U_B = X_{AB}{}^C U_C \,,$$
- Higher-dim info:
$$\mathcal{L}_{U_A} \mathcal{Y}_\Sigma = L_{K_A} \mathcal{Y}_\Sigma = \mathcal{T}_{A\,\Sigma}{}^\Omega \mathcal{Y}_\Omega \,.$$

Mass matrix:

$$\mathbb{M}^{(\mathrm{scalar})}_{I\Sigma,J\Omega} = \mathbb{M}^{(0)}_{IJ}\,\delta_{\Sigma\Omega} + \delta_{IJ}\,\mathbb{M}^{(\mathrm{spin-2})}_{\Sigma\Omega} + \mathcal{N}_{IJ}{}^C \mathcal{T}_{C,\Omega\Sigma}$$

- Lower-dim SUGRA mass matrix $\mathbb{M}^{(0)}_{IJ}$
- Spin-2 mass matrix $\mathbb{M}^{(\mathrm{spin-2})}_{\Sigma\Omega} = \mathcal{T}_{A,\Sigma\Lambda}\mathcal{T}_{A,\Lambda\Omega}$

Mass matrix

- Lower-dim info:

$$\mathcal{L}_{U_A} U_B = X_{AB}{}^{C} U_C \,,$$

- Higher-dim info:

$$\mathcal{L}_{U_A} \mathcal{Y}_{\Sigma} = L_{K_A} \mathcal{Y}_{\Sigma} = \mathcal{T}_{A\,\Sigma}{}^{\Omega} \mathcal{Y}_{\Omega} \,.$$

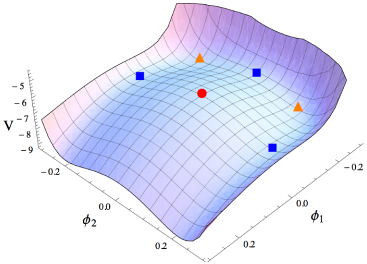
Mass matrix:

$$\mathbb{M}^{(\mathrm{scalar})}_{I\Sigma,J\Omega} = \mathbb{M}^{(0)}_{IJ}\,\delta_{\Sigma\Omega} + \delta_{IJ}\,\mathbb{M}^{(\mathrm{spin-2})}_{\Sigma\Omega} + \mathcal{N}_{IJ}{}^{C}\mathcal{T}_{C,\Omega\Sigma}$$

- Lower-dim SUGRA mass matrix $\mathbb{M}^{(0)}_{IJ}$
- Spin-2 mass matrix $\mathbb{M}^{(\mathrm{spin-2})}_{\Sigma\Omega} = \mathcal{T}_{A,\Sigma\Lambda}\mathcal{T}_{A,\Lambda\Omega}$
- Key object:

$$\mathcal{N}_{IJ}{}^{C} = -4(X_{CA}{}^{B} + 12\,X_{AB}{}^{C})\mathcal{P}^{AD}{}_{[I}\mathcal{P}^{BD}{}_{J]} \,.$$

KK spectroscopy at less symmetric point



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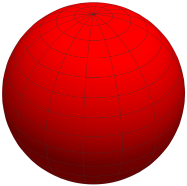
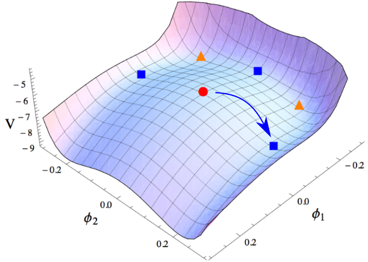
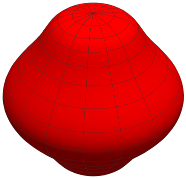


KK spectroscopy at less symmetric point



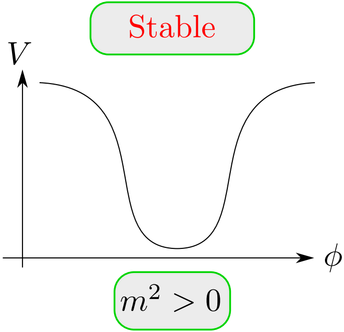
$\longleftrightarrow$



Multiplication by $E_{7(7)}$ matrix, $M_{AB}(x)$!

Use same harmonics as for max. symmetric point

Stability of non-SUSY AdS_4 vacua



Zero-mode vs higher-dimensional stability

Most non-SUSY vacua already unstable in lower-dim theory

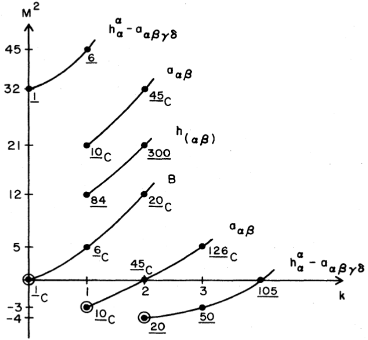
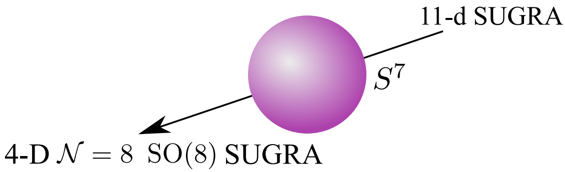


FIG. 2. Mass spectrum of scalars.

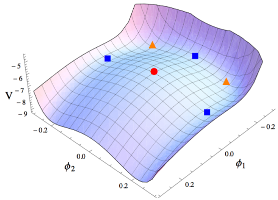
Is “zero-mode” stability enough?

Non-SUSY SO(3)× SO(3) AdS$_4$ vacua

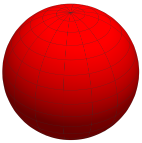


[de Wit, Nicolai '82], [Hohm, Samtleben '14], [Lee, Strickland-Constable, Waldram '14] [Godazgar, Godazgar, Kruger, Nicolai, Pilch '14]

- Non-SUSY SO(3) × SO(3) AdS$_4$ vacuum [Warner '83]

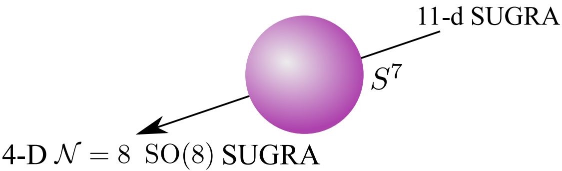


$\longleftrightarrow$



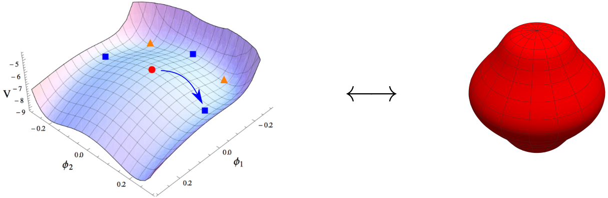
- Only non-SUSY vacuum that is stable in 4-d! [Fischbacher, Pilch, Warner '10], [Comsa, Firsching, Fischbacher '19]

Non-SUSY SO(3)× SO(3) AdS$_4$ vacua



[de Wit, Nicolai '82], [Hohm, Samtleben '14], [Lee, Strickland-Constable, Waldram '14]
[Godazgar, Godazgar, Kruger, Nicolai, Pilch '14]

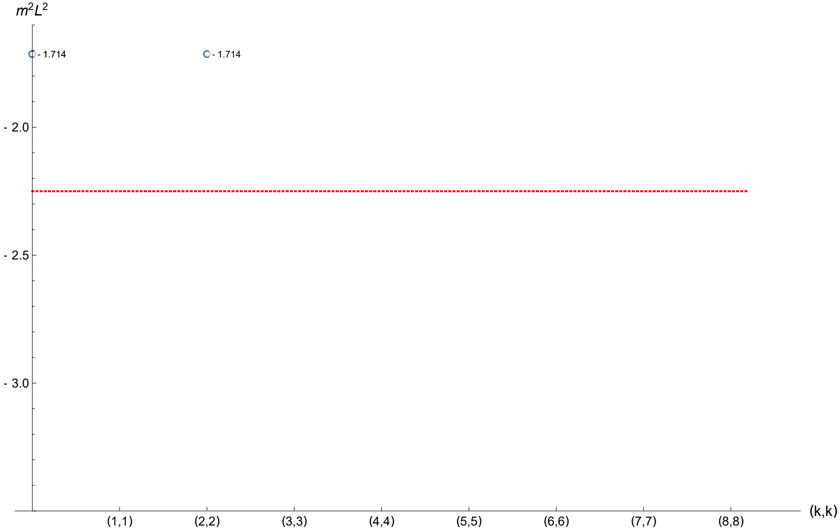
- Non-SUSY SO(3) $\times$ SO(3) AdS$_4$ vacuum [Warner '83]



- Only non-SUSY vacuum that is stable in 4-d! [Fischbacher, Pilch, Warner '10], [Comsa, Firsching, Fischbacher '19]

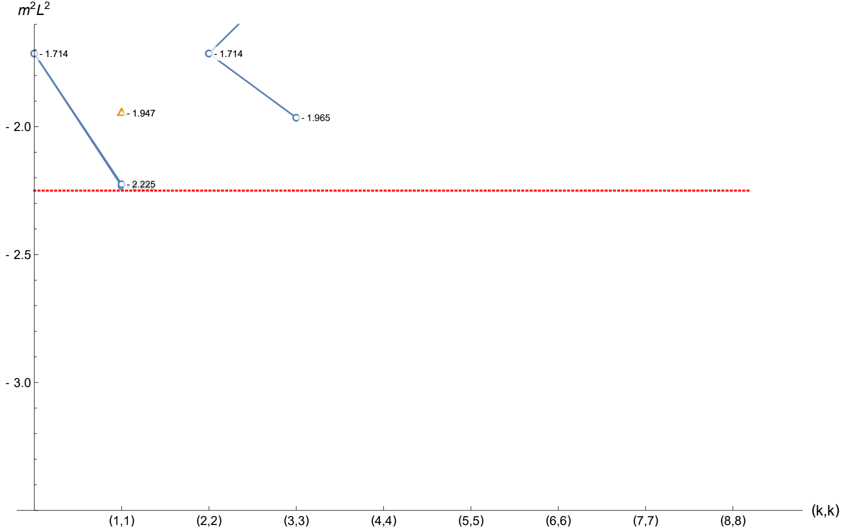
Tachyonic KK modes

Modes $\ell = 0$: $\mathcal{N} = 8$ supergravity multiplet [Fischbacher, Pilch, Warner '10]



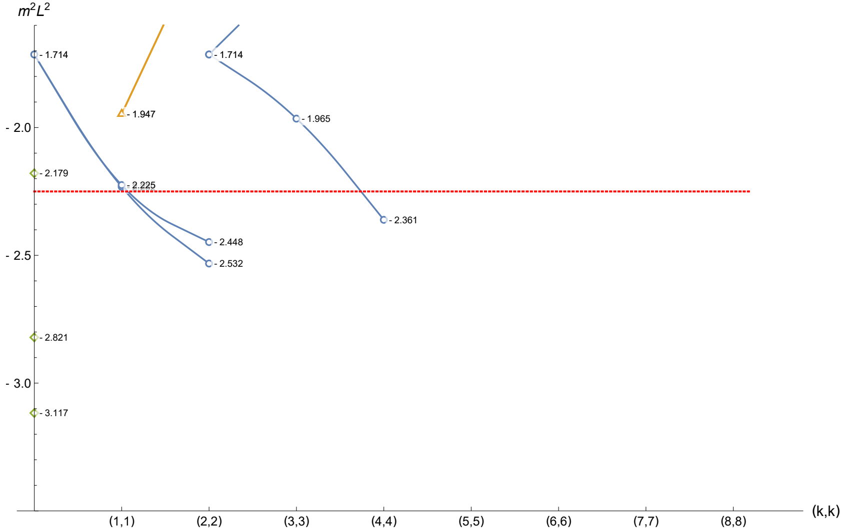
Tachyonic KK modes

Modes $\ell \leq 1$: still stable! [EM, Nicolai, Samtleben JHEP '20]



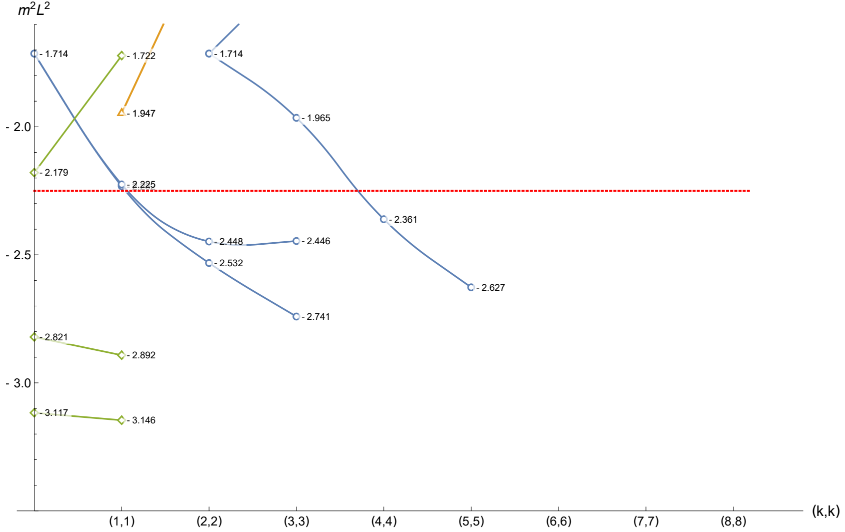
Tachyonic KK modes

Modes $\ell \leq 2$: **tachyons!** [EM, Nicolai, Samtleben JHEP '20]



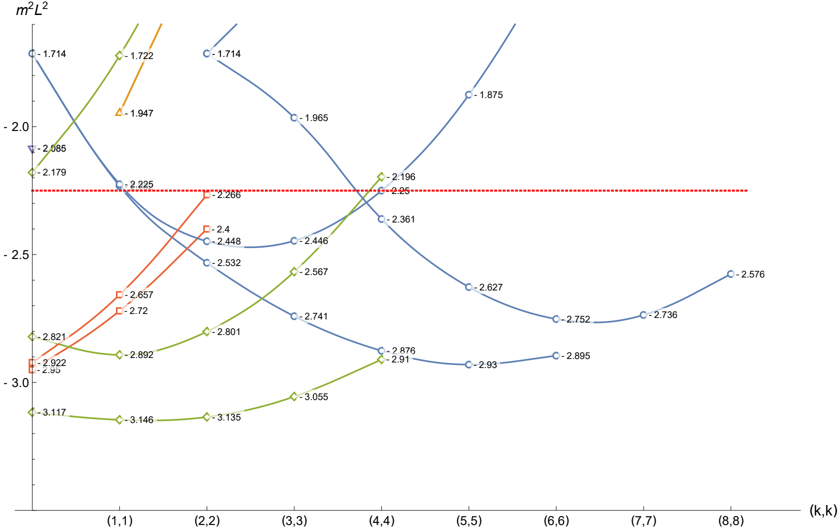
Tachyonic KK modes

Modes $\ell \leq 3$ [EM, Nicolai, Samtleben JHEP '20]



Tachyonic KK modes

Modes $\ell \leq 6$ [EM, Nicolai, Samtleben JHEP '20]



A false hope

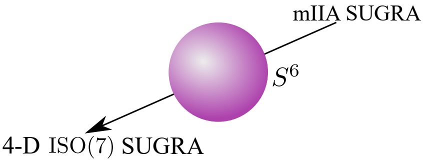
- $SO(3) \times SO(3)$ AdS_4 [Warner '83] is unstable
- Instability from higher KK modes [EM, Nicolai, Samtleben JHEP '20]

> "Zero-mode" stability does not guarantee perturbative stability in higher dimensions

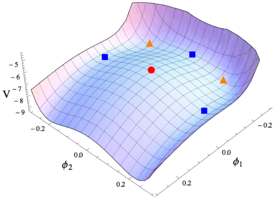
- Also "brane-jet instability" [Bena, Pilch, Warner '20]

Zero-mode stability in ISO(7) SUGRA

- [Guarino, Jafferis, Varela '15]



- 7 stable non-SUSY AdS_4 vacua



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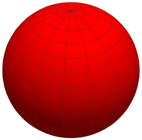

- G_2 invariant + 6 less symmetric non-SUSY AdS_4, stable in 4-D

Zero-mode stability in ISO(7) SUGRA

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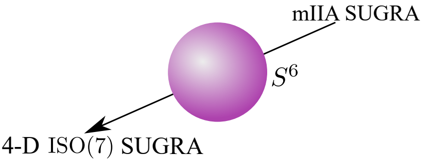
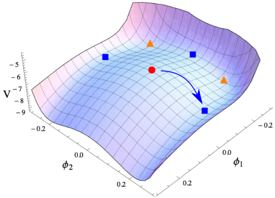
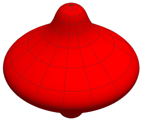


- 7 stable non-SUSY AdS_4 vacua



$\longleftrightarrow$



- G_2 invariant + 6 less symmetric non-SUSY AdS_4, stable in 4-D

Stability of G_2 vacuum in mIIA

- Analytic spectrum:

$$L^2 \mathbb{M}^2_{\text{(scalar)}} = (\ell + 2)(\ell + 3) - \frac{3}{2}\mathcal{C}_{G_2} \geq 0\,.$$

ℓ: S^6 KK level
$\mathcal{C}_{G_2}$: G_2 Casimir

> G_2 vacuum is perturbatively stable in mIIA SUGRA
> [Guarino, EM, Samtleben PRL '21]

- No signs of Ooguri-Vafa instability [Guarino, Tarrio, Varela '20]
- Protected against "bubble of nothing"
- May suffer from different non-perturbative instabilities [Bomans, Cassani, Dibitetto, Petri '21]

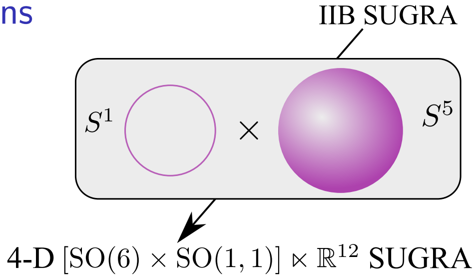
Stability of six other AdS_4 vacua in mIIA

Evidence for perturbative stability in mIIA SUGRA
[Guarino, EM, Samtleben PRL '21]

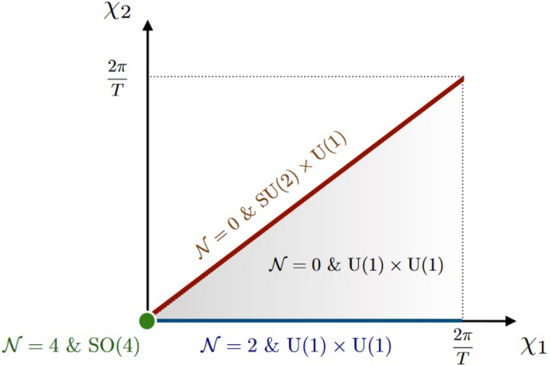
- Numerical evaluation up to level $\ell = 4$:
  - no tachyons
  - lowest-lying masses increase monotonically with level
- No signs of Ooguri-Vafa instability [Guarino, Tarrio, Varela '20]
- Protected against "bubble of nothing"

Non-SUSY flat deformations

- [Inverso, Samtleben, Trigiante '16]



- 2-parameter (χ_1, χ_2) family of AdS_4 vacua [Guarino, Sterckx '21]



IIB S-fold geometry

$\mathrm{AdS}_4 \times S^5 \times S^1$ *S-fold* vacua of IIB String Theory

SL$(2,\mathbb{Z})_{\mathrm{IIB}}$ monodromy along S^1

[Hull, Catal-Özer '03]

$$\mathcal{J}_k = \begin{pmatrix} k & -1 \\ 1 & 0 \end{pmatrix} \in \mathrm{SL}(2,\mathbb{Z})$$

Reduce on S^5, $\chi_{1,2} \longleftrightarrow$ Wilson lines of KK vector

$\chi_{1,2}$ locally coordinate redefinition, but not globally

c.f. $\mathbb{C}$-structure moduli of T^2

Non-SUSY conformal manifold?

Non-SUSY exactly marginal deformations not expected to exist

Evidence for a miracle

[Giambrone, Guarino, EM, Samtleben, Sterckx, Trigiante 2112.11966]

- Perturbative stability
- Non-perturbative stability
- Perturbative quantum corrections

χ_1, χ_2 deformations are locally coordinate transformations!

KK Spectroscopy

[Giambrone, Guarino, EM, Samtleben, Sterckx, Trigiante 2112.11966]

KK spectroscopy $\rightarrow$ full KK spectrum

Perturbatively stable!

At $\chi_{1,2} = 0$, $\mathcal{N} = 4$ point

$$\mathbb{M}^2_{(\mathrm{spin}-2)} L^2 = \frac{1}{2}\ell(\ell+4) + \ell_1(\ell_1+1) + \ell_2(\ell_2+1) + \frac{1}{2}\left(\frac{2n\pi}{T}\right)^2$$

SO(4) spin: ℓ_1, ℓ_2,
S^5 level: ℓ
S^1 level: n

KK Spectroscopy

[Giambrone, Guarino, EM, Samtleben, Sterckx, Trigiante 2112.11966]

KK spectroscopy → full KK spectrum

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SO(4) spin: ℓ_1, ℓ_2,
S^5 level: ℓ
S^1 level: n

$$\frac{2n\pi}{T} \longrightarrow \frac{2n\pi}{T} + j_1\chi_1 + j_2\chi_2$$

$j_{1,2}$ carges under $U(1) \times U(1)$ Cartan

Space invaders: $\chi_{1,2} \to \chi_{1,2} + \frac{4\pi}{T}$, $n \to n - 2\,j_{1,2}$

Non-perturbative stability?

[Giambrone, Guarino, EM, Samtleben, Sterckx, Trigiante 2112.11966]

- Probe-brane analysis: $T > Q$
  Branes more stable than in SUSY case!
- No Ooguri-Vafa instability [Ooguri, Vafa '16]
- S^1 and S^5 protected against "bubble of nothing" [Witten '82]
- D3-brane bubble of nothing [Bomans, Cassani, Dibitetto, Petri '21] ??

Beyond "large-N" limit

[Giambrone, Guarino, EM, Samtleben, Sterckx, Trigiante 2112.11966]

Moduli $\chi_{1,2}$ not lifted by perturbative quantum (α', g_s) corrections

Protection by diffeomorphism symmetry

- χ_1, χ_2 $\rightarrow$ coordinate transformations (locally)
- χ_1, χ_2 do not appear in diffeo-invariant quantities

Also applies to $\mathcal{N} = 1$ exactly marginal deformations

[Bobev, Gautason, van Muiden '21]

Non-perturbative corrections?

Flat directions lifted by non-perturbative corrections?

- 5-brane instantons on $S^5 \times S^1$
- Classical instanton action $e^{-vol_{S^5\times S^1}}$ invariant under χ_1, χ_2
- Instanton amplitude sensitive to $\chi_{1,2}$?

Applications to SUSY AdS

AdS KK spectrum $\Longleftrightarrow$ anomalous dimensions of CFT operators

- U(3) $\mathcal{N} = 2$ AdS_4 vacuum [Corrado, Pilch, Warner '02]
  $\Rightarrow$ Full spectrum [EM, Samtleben '20]

- U(2) $\mathcal{N} = 2$ AdS_5 vacuum [Pilch, Warner '00]
  $\Rightarrow$ Full spectrum & check with LS SCFT [Bobev, EM, Robinson, Samtleben, van Muiden '20]

- AdS_5 S-folds [Inverso, Samtleben, Trigiante '16], [Guarino, Sterckx, Trigiante '20]
  $\Rightarrow$ Full spectrum & compactness of conformal manifold [Giambrone, EM, Samtleben, Trigiante '21]

Conclusions

ExFT: powerful tool to construct non-SUSY AdS vacua & determine perturbative stability

- Perturbative non-SUSY AdS vacua with possible protection against non-perturbative instability
- (SUSY) AdS vacua: KK spectrum $\Leftrightarrow$ Anomalous dimensions

Open questions

- Vacua of less SUSY gSUGRA?
- $\Lambda \geq 0$?
- Non-perturbative stability? Positive Mass Theorem? [Dibitetto '21]
- Non-perturbative correction?

Thank you!