dS vacua and the swampland

Timm Wrase

Discrete 2018, Vienna November 29th, 2018

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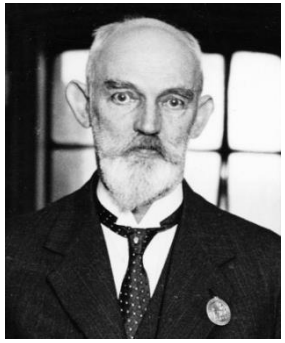
Outline

- The dS swampland conjecture

- Status of dS vacua in string theory



- Conclusion

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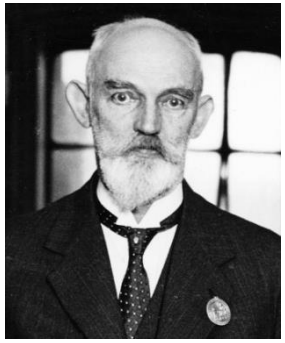
- Status of dS vacua in string theory

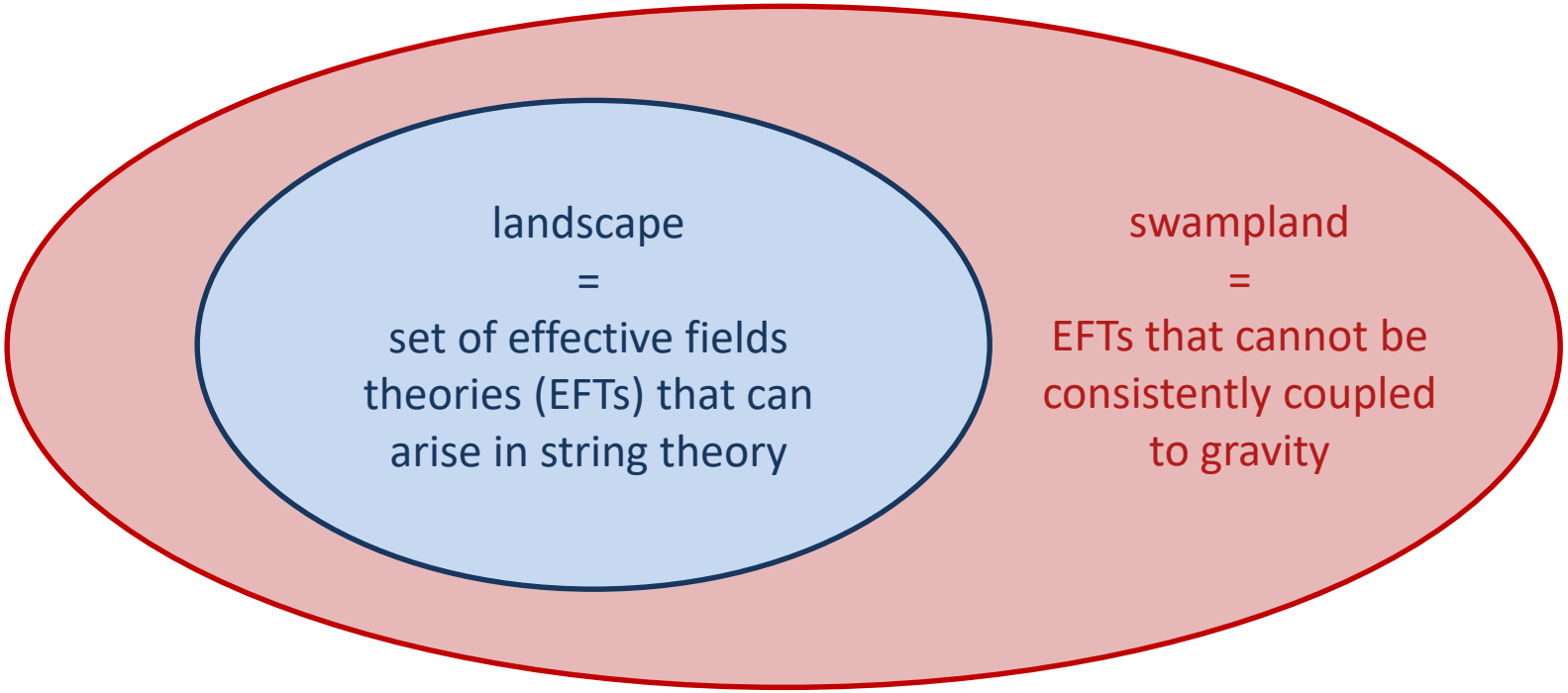


- Conclusion

The swampland

- Not every low energy effective action can be consistently coupled to gravity
- It has been always conjectured that not everything goes

Brennan, Carta, Vafa 1711.00864



The swampland

- Not every low energy effective action can be consistently coupled to gravity
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Brennan, Carta, Vafa 1711.00864

- How can we chart the boundaries of the swampland/landscape?
- Exists in string theory $\Rightarrow$ landscape

The swampland

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Brennan, Carta, Vafa 1711.00864

- How can we chart the boundaries of the swampland/landscape?
- Exists in string theory ⇒ landscape
- Does not exist in string theory ⇒ swampland
  or work harder
  or need to understand non-perturbative string theory

The swampland

Nevertheless often real progress can be made:

- One nice example is 10d $N = 1$ supergravity
- There are two heterotic string theories, the $E_8 \times E_8$ and the $SO(32)$ string (related to type I)

The swampland

Nevertheless often real progress can be made:

- One nice example is 10d $N = 1$ supergravity
- There are two heterotic string theories, the $E_8 \times E_8$ and the $SO(32)$ string (related to type I)
- There are in principle other seemingly anomaly free 10d $N = 1$ supergravity theories with gauge groups: $E_8 \times U(1)^{248}$ and $U(1)^{496}$
- These are in the swampland and actually anomalous

Adams, DeWolfe, Taylor 1006.1352

The swampland

- Not every low energy effective action can be consistently coupled to gravity
- It has been always conjectured that not everything goes

Brennan, Carta, Vafa 1711.00864

I. No global symmetries
II. All charges appear
III. Finite number of massless fields
IV. No free parameters
V. Non-compact moduli space

VI. Distance conjecture
VII. Simply connected moduli space
VIII. Weak gravity conjecture
IX. No AdS/CFT without SUSY
X. No de Sitter vacua

The swampland

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dS extrema and the swampland

Recent papers call for a paradigm change

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Danielsson, Van Riet 1804.01120
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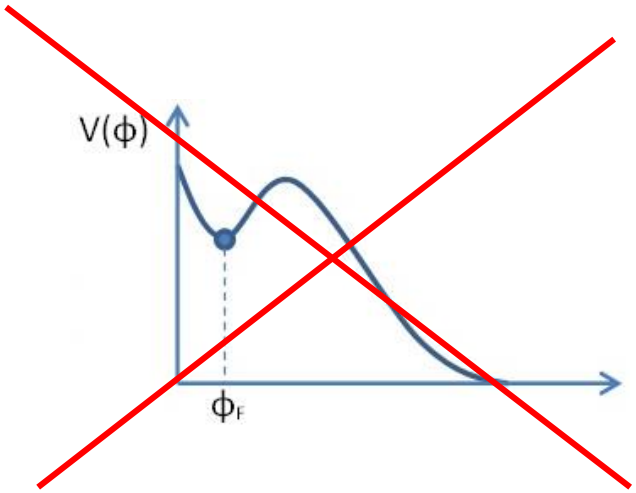
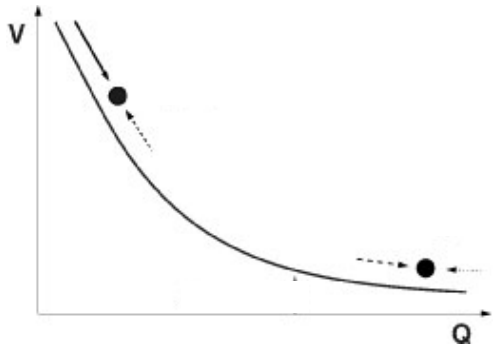
Agrawal, Obied, Steinhardt, Vafa 1806.09718

$$|\nabla V| \geq c\, V \quad \text{for} \quad c \sim O(1)$$





dS extrema and the swampland

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$$|\nabla V| \geq c\, V \quad \text{for} \quad c \sim O(1)$$

Inflation $\overset{?}{\Rightarrow}$ string gas cosmology, bouncing cosmology, …

dS vacua $\Rightarrow$ quintessence

dS extrema and the swampland

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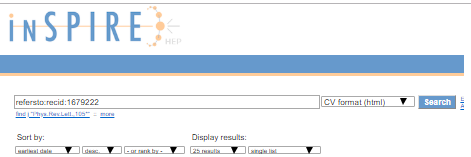
$$|\nabla V| \geq c\, V \quad \text{for} \quad c \sim O(1)$$

Inflation $\overset{?}{\Leftrightarrow}$ current experimental bound $c \leq .09$, $\nabla V \leq .09V$

dS vacua $\Rightarrow$ quintessence $V(\phi) \sim e^{c\phi}$ bound $c < .54, \nabla V \leq .5V$



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By Clara Moskowitz on July 30, 2018

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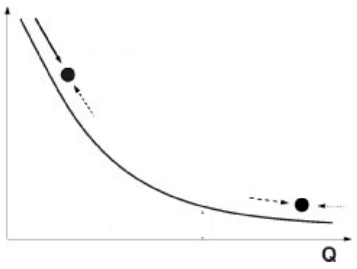
KOSMOLOGIE

Führt die Stringtheorie ins Sumpfland?

The dS swampland conjecture

- The dS swampland conjecture is *currently* compatible with our universe, $c_{dark\ energy} < .54 \approx O(1)$



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  - $M_P \to \infty$ makes it trivial: $\mathrm{M}_P|\nabla V| \geq c\ V$

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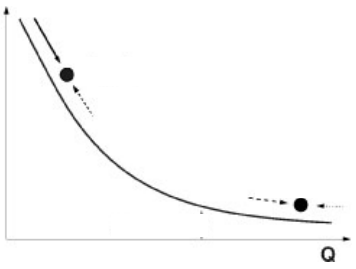


- It passes consistency checks:
  - $M_P \to \infty$ makes it trivial: $\mathrm{M}_P|\nabla V| \geq c\, V$
  - Condition is trivial for Minkowsi and AdS vacua $\mathrm{V} \leq 0$
  - Quadratic potentials are ok, $V = \frac{1}{2}m^2\phi^2$:

$$\frac{\mathrm{M}_P|\nabla V|}{V} = \frac{2\,\mathrm{M}_P}{\phi} \geq c, \text{ for } \phi < M_P \text{ (SDC)}$$

The dS swampland conjecture

- What is the conjecture based on?
  1. Existing debate about the correctness of KKLT and other constructions of dS vacua
  2. Absence of simple dS vacua in string theory (for example with large cc in D-dimension)
  3. Many explicit and simple setups do not give rise to dS but satisfy the conjecture with $c > 1$, e.g.
     - M-theory on smooth G_2 manifolds
     - non-SUSY $O(16) \times O(16)$ heterotic string
     - classical type II flux compactifications with restricted ingredients (see below)

The dS swampland conjecture

- What is the conjecture *not* based on?

1. Explicit calculations that show how all the existing counter-examples to the conjecture are wrong*

   *) admittedly very difficult because there are many

2. Discussion of one or more explicit problems in KKLT that the authors believe to be fatal

The dS swampland conjecture

- The original conjecture is in tension with the Higgs potential (and pion potential)

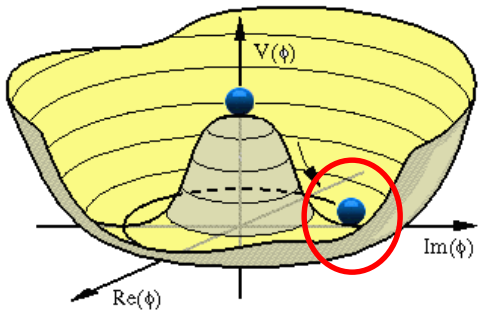
Denef, Hebecker, Wrase 1807.06581
Cicoli, De Alwis, Maharana, Muia, Quevedo 1808.08967
Murayama, Yamazaki, Yanagida 1809.00478
Choi, Chway, Shin 1809.01475
Hamaguchi, Ibe, Moroi 1810.02095

$|\nabla V| \geq c\, V$ for $c \sim O(1)$

If $V(\phi, H) = V_\phi(\phi) + V_H(H)$, then for

$H = H_{min}$ we have

$\nabla V = \partial_\phi V = \partial_\phi V_\phi \approx .54\, V \approx 10^{-120} M_P^4$



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Denef, Hebecker, Wrase 1807.06581
Cicoli, De Alwis, Maharana, Muia, Quevedo 1808.08967
Murayama, Yamazaki, Yanagida 1809.00478
Choi, Chway, Shin 1809.01475
Hamaguchi, Ibe, Moroi 1810.02095

$|\nabla V| \geq c\, V$ for $c \sim O(1)$

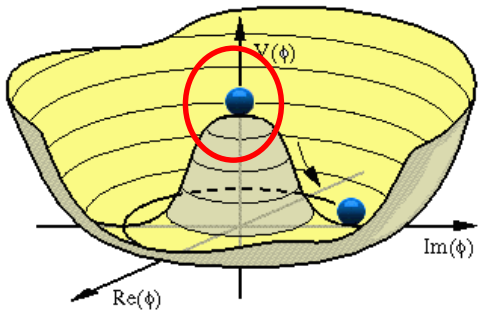
If $V(\phi, H) = V_\phi(\phi) + V_H(H)$, then for

$H = H_{min}$ we have

$$\nabla V = \partial_\phi V = \partial_\phi V_\phi \approx .54\, V \approx 10^{-120} M_P^4$$

and for $H = 0$ we have

$$\nabla V = \partial_\phi V = \partial_\phi V_\phi \approx 10^{-120} M_P^4 \ll \Lambda_{EW}$$



The dS swampland conjecture

- One would have to couple the very light quintessence scalar ϕ to the Standard Model, e.g.

$$V(H,\phi) = e^{-c\phi} V_H(H)$$

- This leads to a fifth forth/equivalence principle violation and needs to be compatible with all current observations
- This seems very difficult for $c \sim O(1)$ (similar problem for π_0)

Choi, Chway, Shin 1809.01475

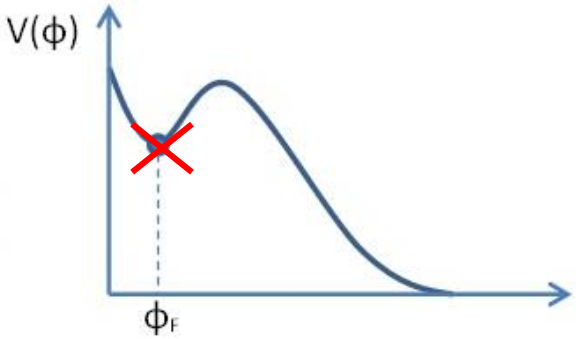
The dS swampland conjecture

- The refined dS swampland conjecture states

Dvali, Gomez 1806.10877
Andriot 1806.10999
Garg, Krishnan 1807.05193
Ooguri, Palti, Shiu, Vafa 1810.05506

$$|\nabla V| \geq c\, V \quad \text{or} \quad \min\left(\nabla_i \nabla_j V\right) \leq -c' V \qquad c, c' \sim O(1)$$

This forbids minima but allows dS maxima (that are not overly flat)

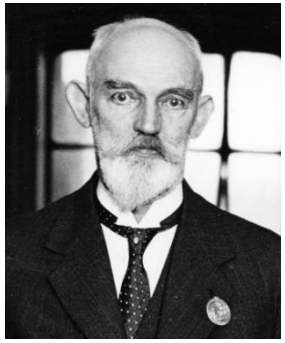


Similar to *no* slow-roll, $\epsilon_V \geq O(1)$ or $\eta_V \leq -O(1)$

Outline

- The dS swampland conjecture

- Status of dS vacua in string theory



- Conclusion

KKLT dS vacua in string theory

- The KKLT scenario of dS vacua can be described in three steps

  Kachru, Kallosh, Linde, Trivedi hep-th/0301240

- Consider type IIB string theory on a warped CY_3 manifold with fluxes
  1. The complex structure moduli and the axio-dilaton are fixed in a SUSY or non-SUSY Minkowski vacuum
  2. Non-perturbative instanton effects stabilize the single volume modulus in an AdS SUSY vacuum
  3. An anti-D3-brane at the bottom of a warped throat uplifts this to a dS vacuum

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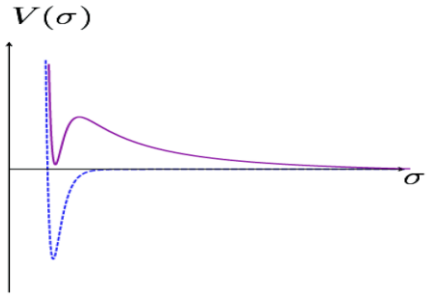
  3. The anti-D3-brane adds a positive term to the scalar potential $V \to V + \frac{\mu^4}{(T+\bar{T})^2}$



KKLT dS vacua in string theory

Criticisms of the KKLT scenario:

1. The single volume modulus receives perturbative corrections so we cannot calculate instanton corrections because it is rolling

Sethi 1709.03554

Kachru, Trivedi 1808.08971

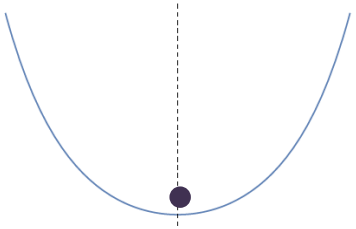


Figure 1: A good starting point.

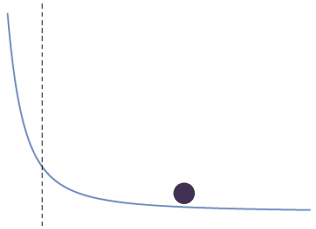


Figure 2: A not so good starting point.

KKLT dS vacua in string theory

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   Sethi 1709.03554

   Kachru, Trivedi 1808.08971

2. Anti-D3-branes have fatal backreaction (?), destabilize throat, problematic tachyons, etc. (Saclay group since 2009)
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4. No dS vacua in 10D description (Hamburg & Stanford groups)

dS vacua in type IIA

- What are the simplest dS vacua one can construct in string theory?
- Answering this questions allows us to scrutinize the *dS swampland conjecture*
- Not relevant for phenomenology
- Probably very relevant for better understanding dS space, dS/CFT, etc.

dS vacua in type IIA

- Using fluxes F_0, F_2, F_4 and H_3 together with O6-planes, one can stabilize all moduli *classically* in AdS_4

DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160

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  DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160

- Once curvature is included, dS vacua seem possible and have been searched for

  Flauger, Robbins, Paban, TW 0812.3886
  Caviezel, Koerber, Körs, Lüst, TW, Zagermann 0812.3551
  Danielsson, Haque, Shiu, Van Riet 0907.2041
  Caviezel, TW, Zagermann 0912.3287
  Danielsson, Koerber, Van Riet 1003.3590

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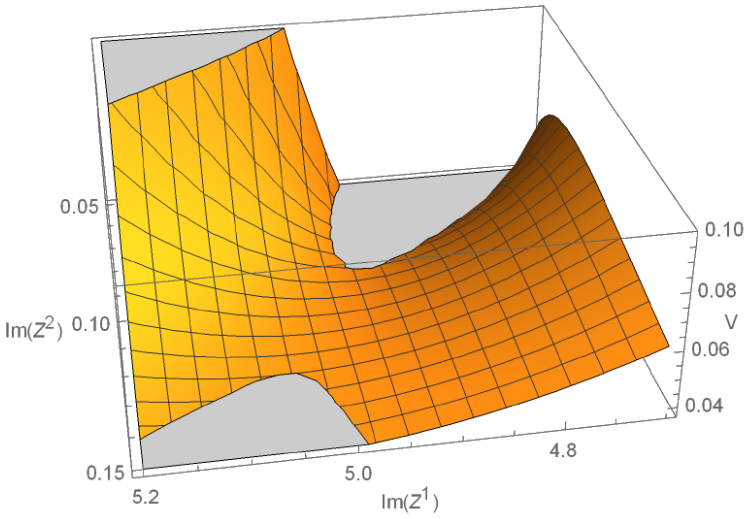
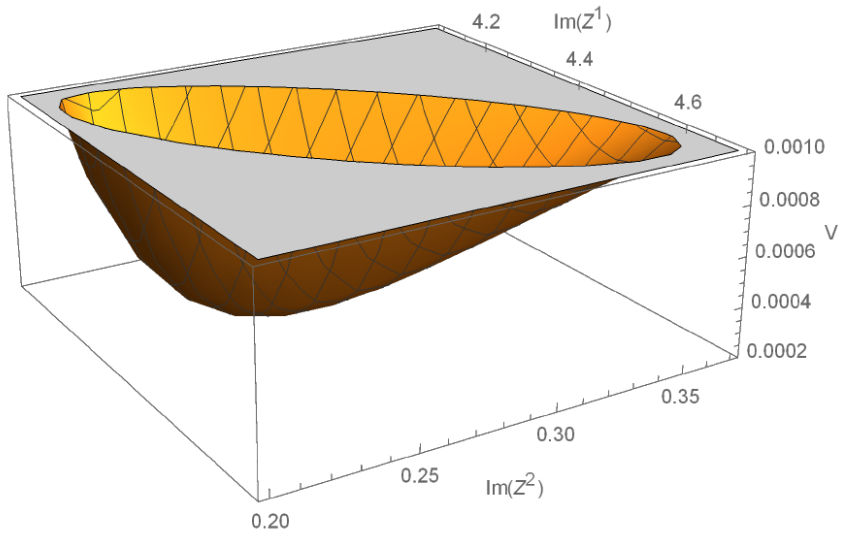
  Caviezel, TW, Zagermann 0912.3287
  Danielsson, Koerber, Van Riet 1003.3590

- No dS vacua have been found in these searches but dS critical points with $|\nabla V| = 0, V > 0$ have been constructed (always one tachyonic direction)

  Junghans 1603.08939
  Junghans, Zagermann 1612.06847

Anti-D6-branes in massive IIA



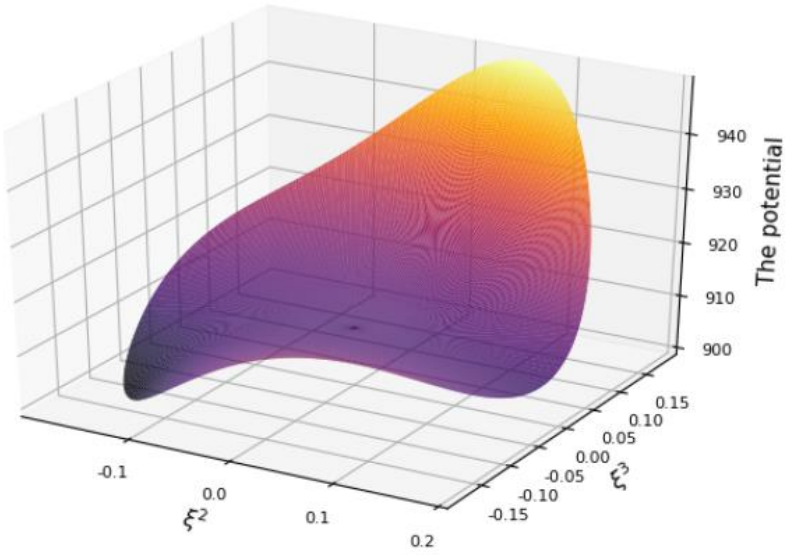


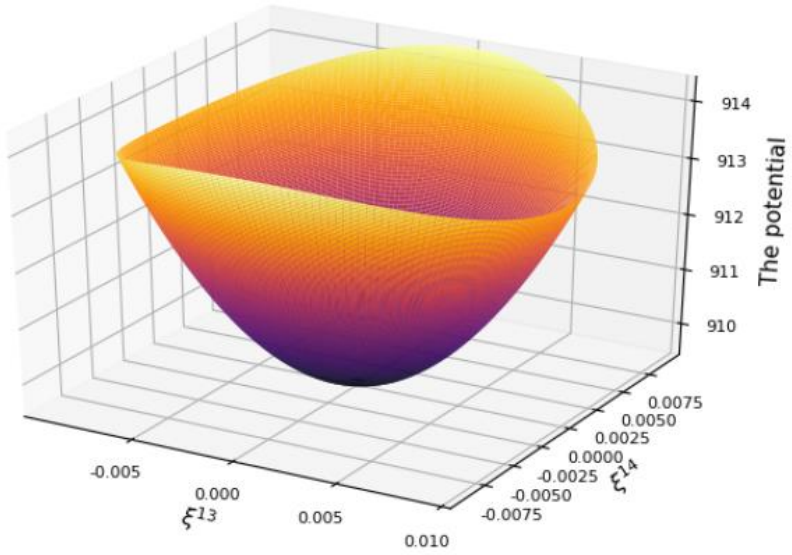
- Checked explicitly in the simplest example $S^3 \times S^3/Z_2 \times Z_2$
- The one obstinate tachyonic direction is now stable
- dS solutions at slightly shifted values, *do not seem to be trustworthy* in this example (small volume, large coupling)

Kallosh, Wrase 1808.09427

Banlaki, Chowdhury, Roupec, Wrase 1811.07880

KK monopoles in massive IIA





- Similarly, stable dS vacua were found by including KK monopoles

  Blåbäck, Danielsson, Dibitetto 1810.11365

- Obstinate tachyon is now gone but one flat direction seems to remain

Conclusion

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THANK YOU!