A Universal Tachyon in Nearly No-scale de Sitter Compactifications

Marco Zagermann
(University of Hamburg)

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Hamburg, June 7, 2017

Mainly based on: Junghans, MZ (2016) 1612.06847

Introduction

This morning:

IR modifications of GR ⟷ Cosmology

→ Shinji Mukohyama's talk

This morning:

IR modifications of GR ⟷ Cosmology

→ Shinji Mukohyama's talk

This talk:

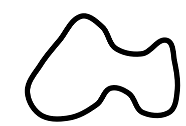
UV modifications of GR (String theory) ⟷ Cosmology

Cf. also Alexander Westphal's talk

String theory is a unified UV-completion of SM interactions and GR

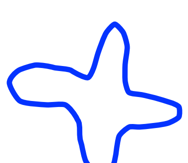
Basic idea:

Apparently point-like particle = "String"

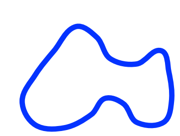


closed or open

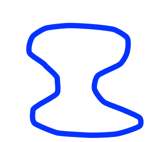
Different point particle species	⟷	Different string vibration modes



↕ Particle type A



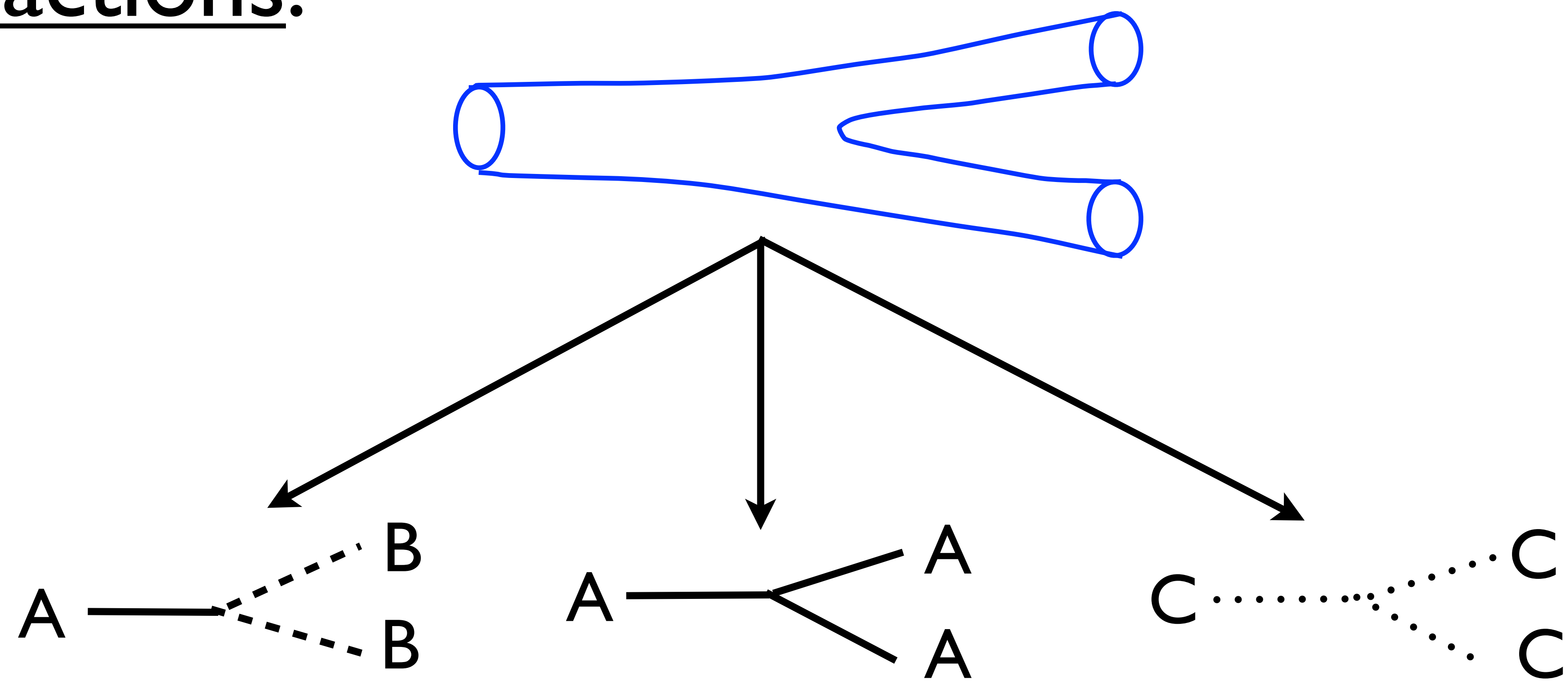
↕ Particle type B



↕ Particle type C

etc.

Interactions:



etc.

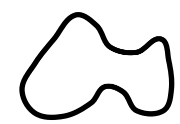
$\ni$ gravity, Yang-Mills, Yukawa etc. at large length scales (small energies)

→ Unified, UV-finite description of all particles and interactions

So far: No deviations from point particle behavior in particle physics experiments

Hence:

$$\textbf{string size} < 10^{-19}\text{m} \sim (1\ \text{TeV})^{-1}$$



$\uparrow$

ΔL_{LHC}

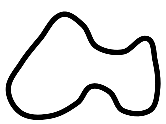
Consistent with

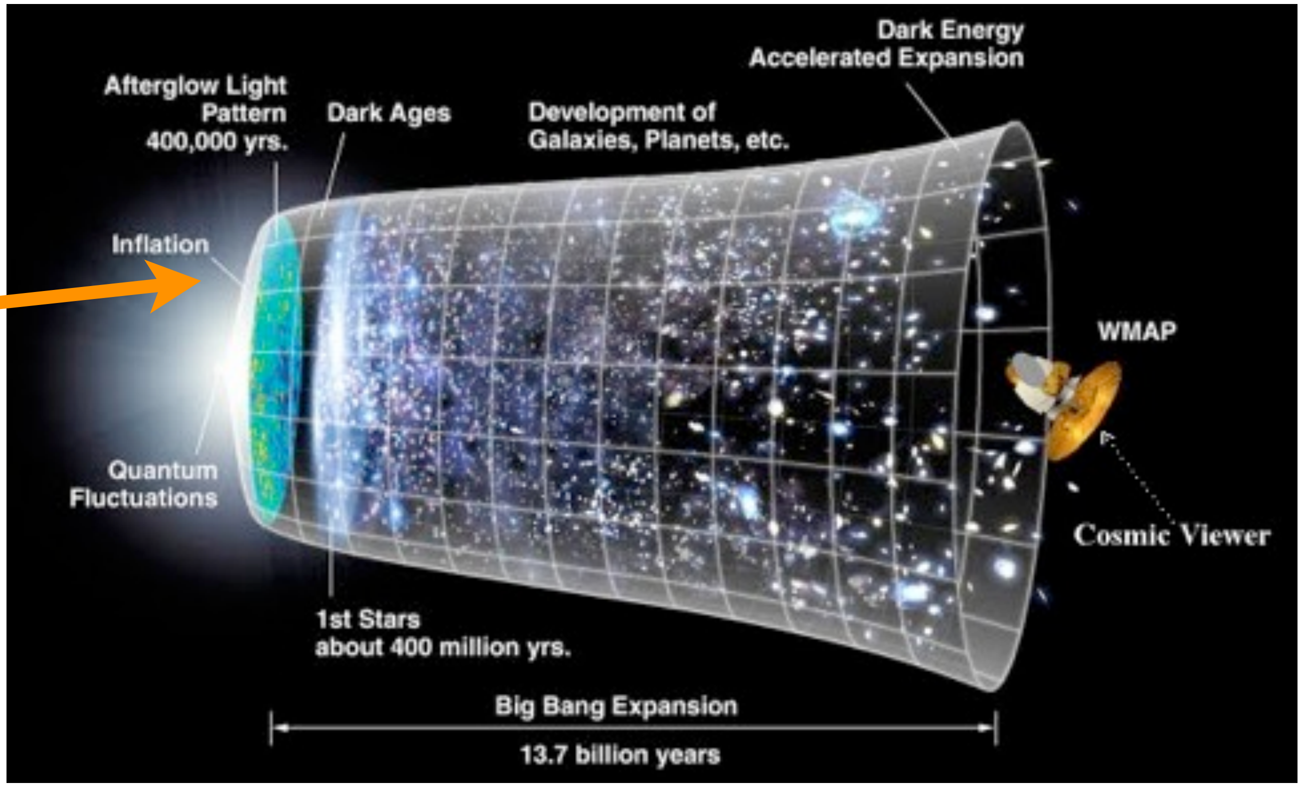
→ Strings must be tiny and directly only affect physics in the deep UV

But: There are also indirect consequences of string theory that may even be relevant for observations at cosmological length scales!

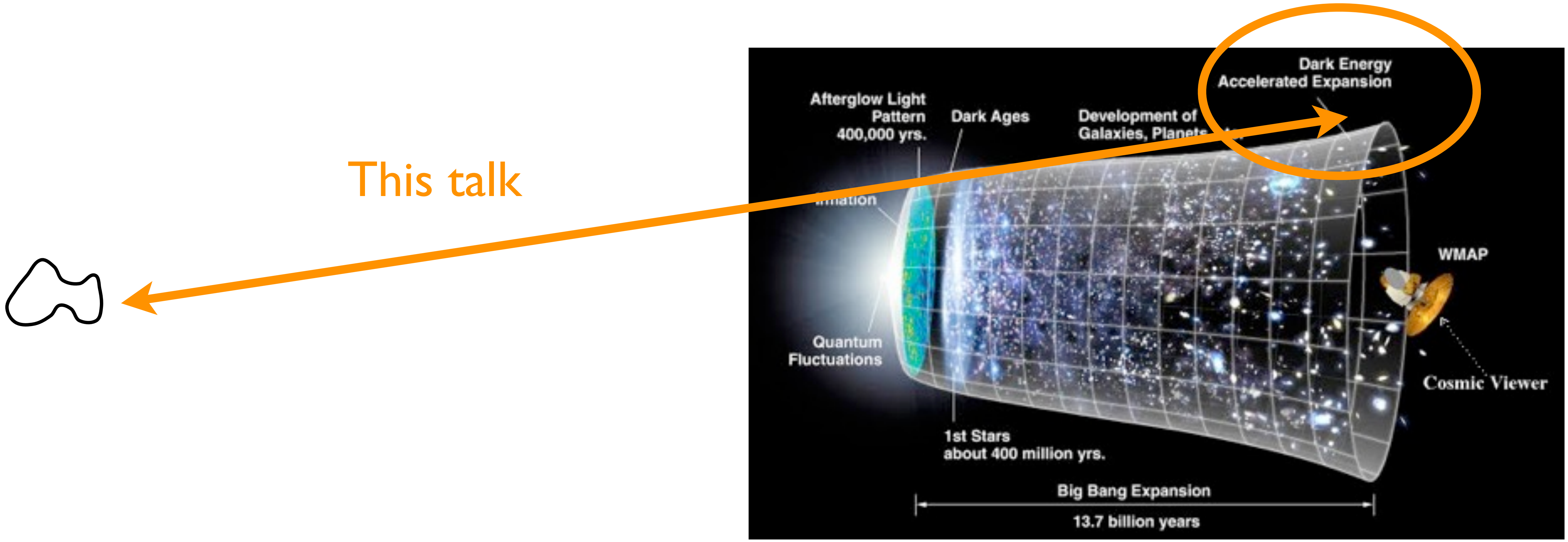
But: There are also indirect consequences of string theory that may even be relevant for observations at cosmological length scales!

E.g. Alexander Westphal's talk

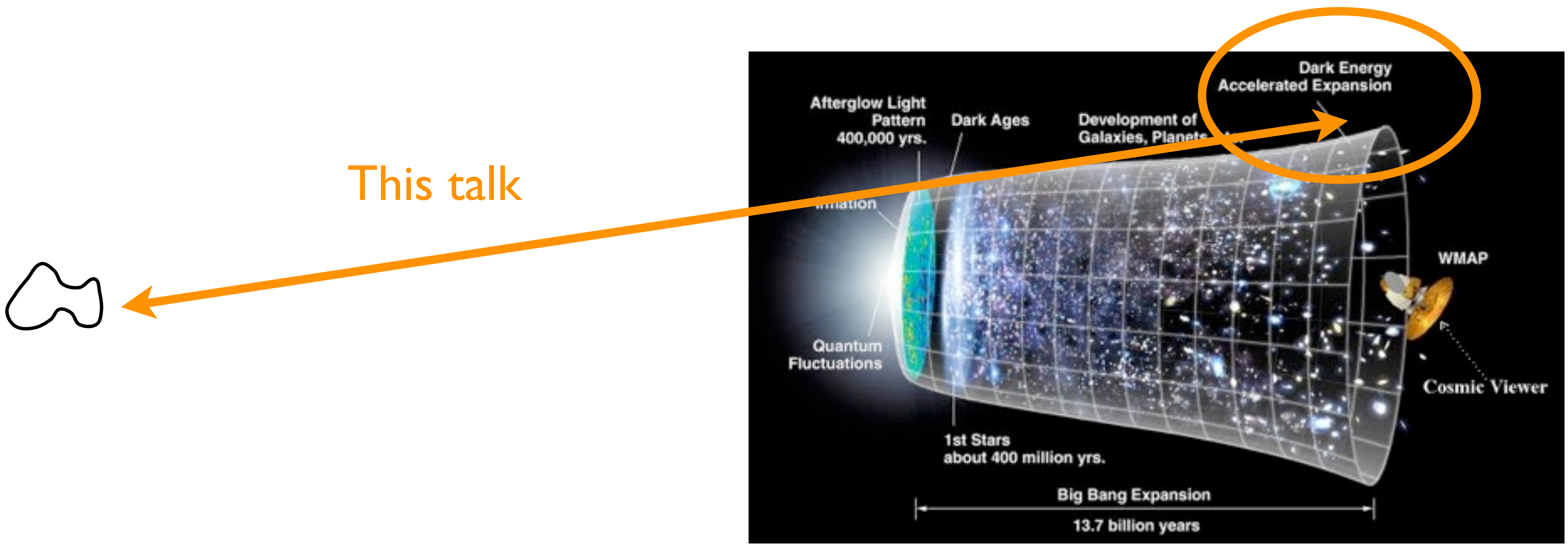




But: There are also indirect consequences of string theory that may even be relevant for observations at cosmological length scales!



<u>But</u>: There are also indirect consequences of string theory that may even be relevant for observations at cosmological length scales!



Implementing a positive cosmological constant ("dark energy") in string theory is surprisingly non-trivial!

Why is that?

Mathematical consistency of string theory requires extra dimensions (and supersymmetry)

Superstrings:	9 spatial + 1 temporal dimensions
Observation:	3 spatial + 1 temporal dimensions

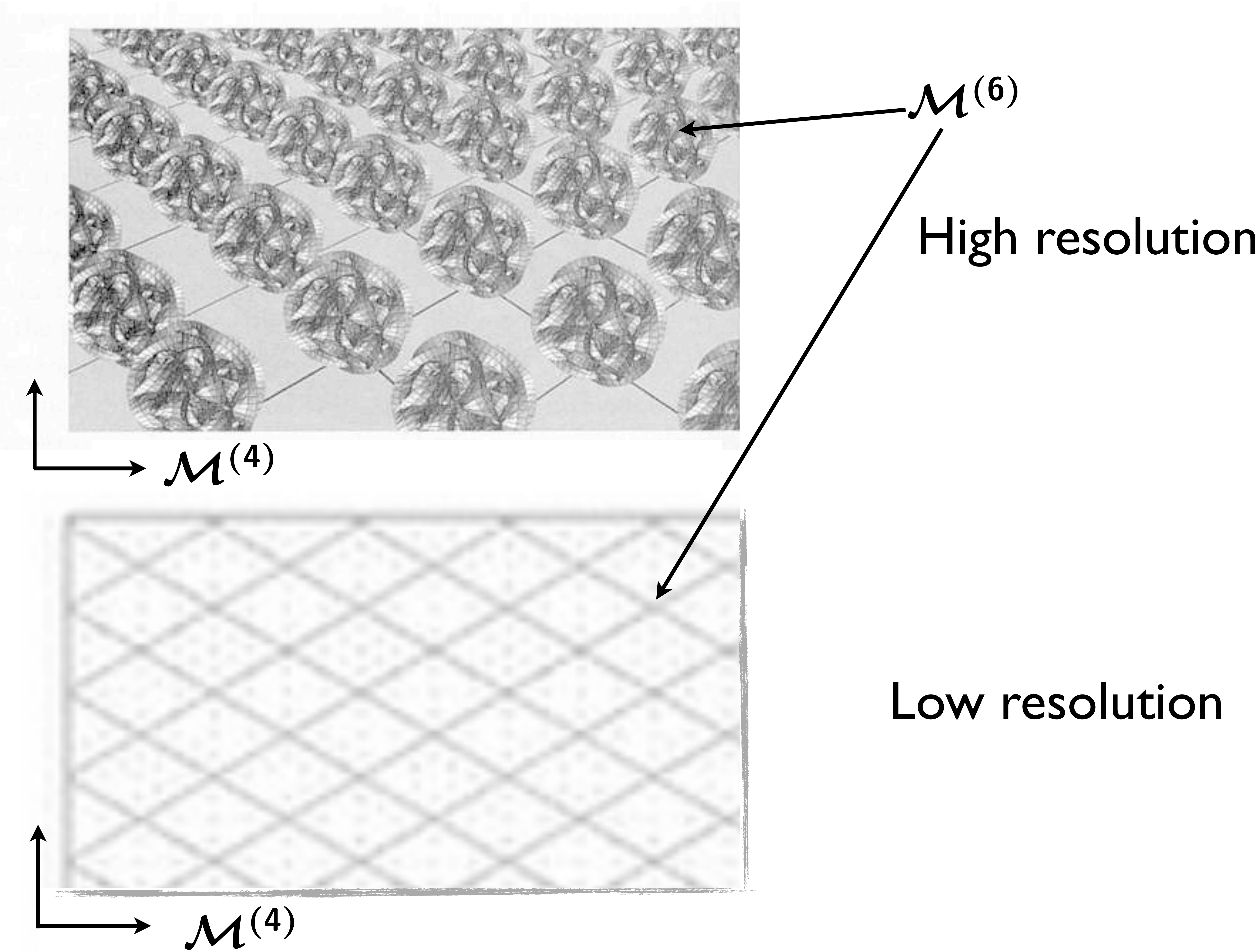
→ Standard scenario: "Compactification"

$$\mathcal{M}^{(10)} = \mathcal{M}^{(4)} \times \mathcal{M}^{(6)}$$

Large & non-compact (= our familiar 4D world)

small & compact (Size R_c)

At length scales $\Delta L >> R_c$ the world looks effectively 4D



$\mathcal{M}^{(6)}$
High resolution
$\mathcal{M}^{(4)}$
Low resolution
$\mathcal{M}^{(4)}$

An important consequence of the extra dimensions:

Moduli fields

Moduli fields:

Light 4D scalar fields from higher dimensional field components:

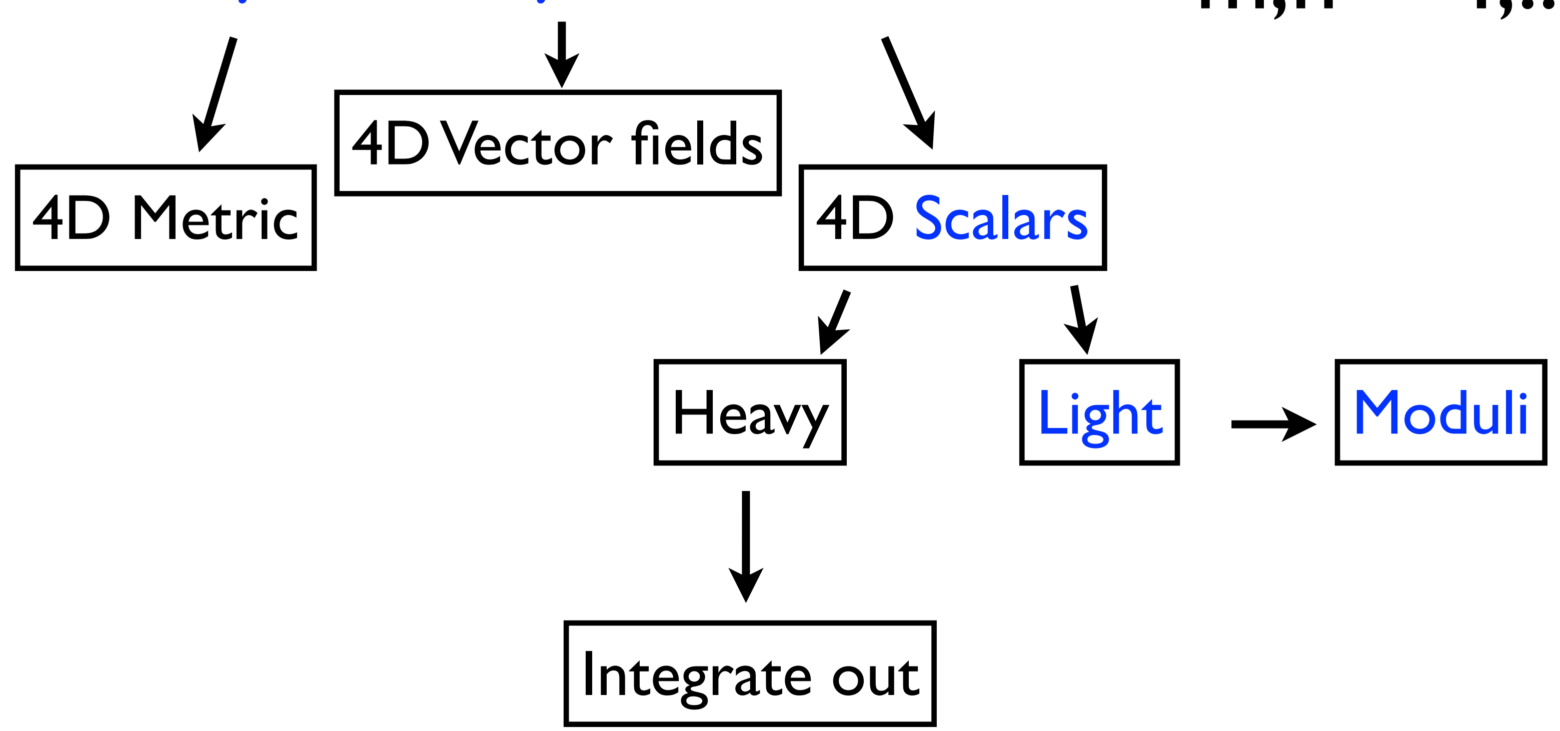
E.g. metric fluctuations:

$M,N = 0,\ldots,9$

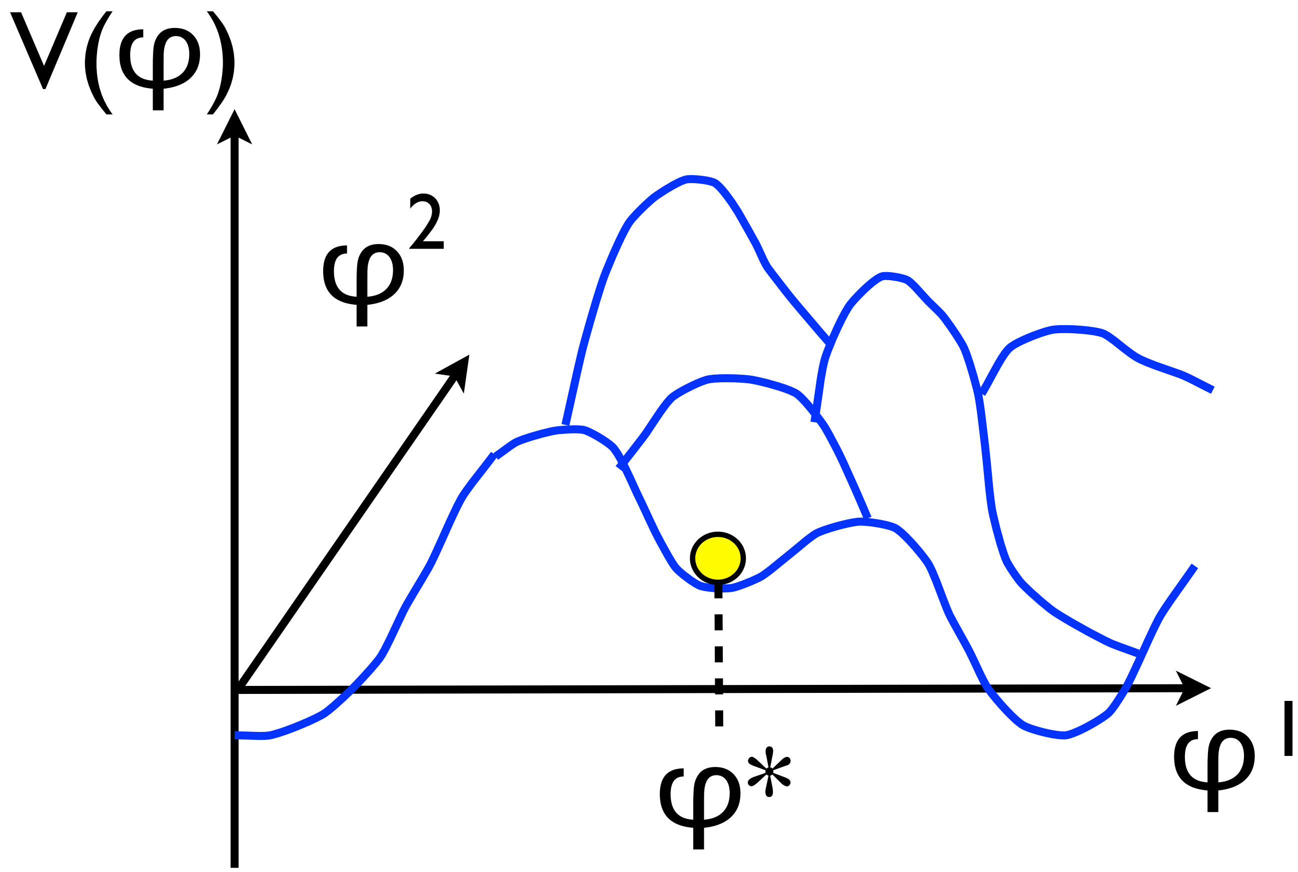
$\mu,\nu = 0,1,2,3$

$m,n = 4,\ldots,9$

$$\delta \mathbf{g}_{\mathrm{MN}} \longrightarrow \delta \mathbf{g}_{\mu\nu} \; , \; \delta \mathbf{g}_{\mu \mathrm{m}} \; , \; \delta \mathbf{g}_{\mathrm{mn}}$$



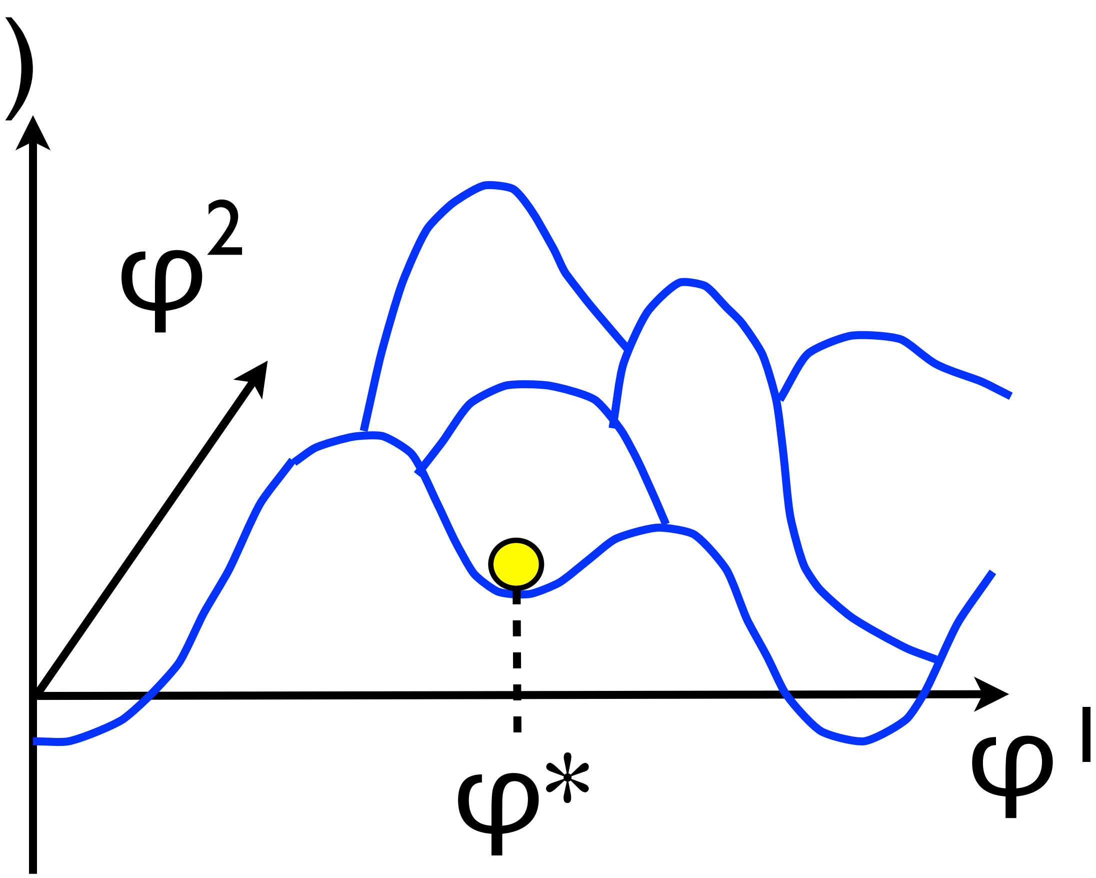
Various effects (tree-level + quantum corrections) generate an effective 4D scalar potential for the moduli



Positive CC ⟷ Local minimum at $V(\varphi^*) > 0$

Ideally: $V(\varphi^*) = \rho_{vac} \approx (1\ \mathrm{meV})^4$ | $M_{moduli} > \mathcal{O}(30\ \mathrm{TeV})$

Various effects (tree-level + quantum corrections) generate an effective 4D scalar potential for the moduli



Main topic of this talk (surprisingly difficult!)

Positive CC ⟷ Local minimum at $V(\varphi^*) > 0$

Ideally: $V(\varphi^*) = \rho_{vac} \approx (1\ \mathrm{meV})^4$

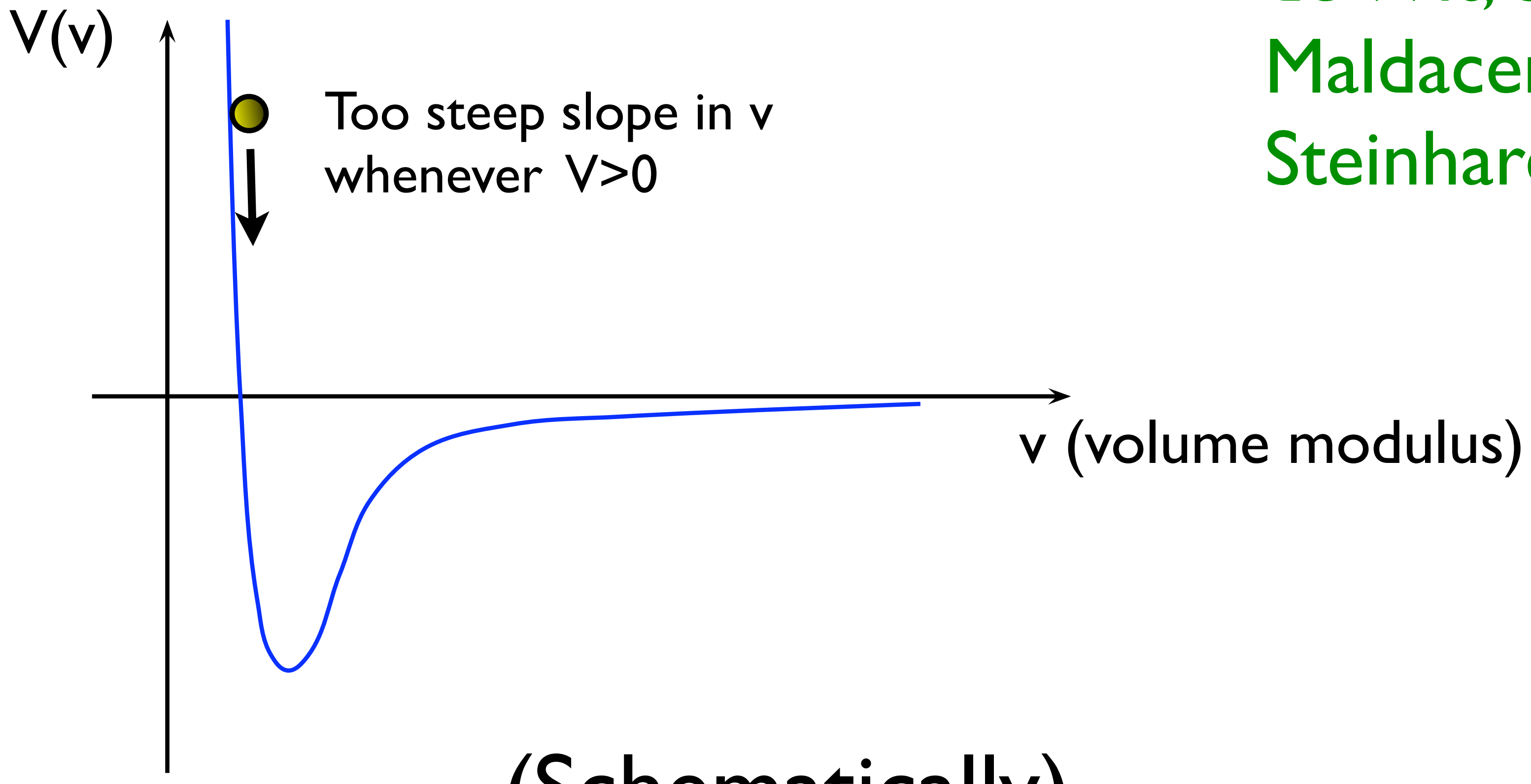
$M_{moduli} > \mathcal{O}(30\ \mathrm{TeV})$

Two problems:

1. Find a critical point with $V(\varphi^*) > 0$

Problem: Simple setups ruled out by no-go theorems

E.g.: Gibbons (1984);
de Wit, Smit, Hari Dass (1987)
Maldacena, Nuñez (2000)
Steinhardt, Wesley (2008)



(Schematically)

Two problems:

1. Find a critical point with $V(\varphi^*) > 0$

Problem: Simple setups ruled out by no-go theorems

→ Need more complicated compactification setups:

Two problems:

1. Find a critical point with $V(\varphi^*) > 0$

<u>Problem</u>: Simple setups ruled out by no-go theorems

→ Need more complicated compactification setups:

1. "Classical de Sitter vacua"

   (Tree-level with orientifolds planes and negative 6D curvature)

   To evade no-go

or

2. "Quantum de Sitter vacua"

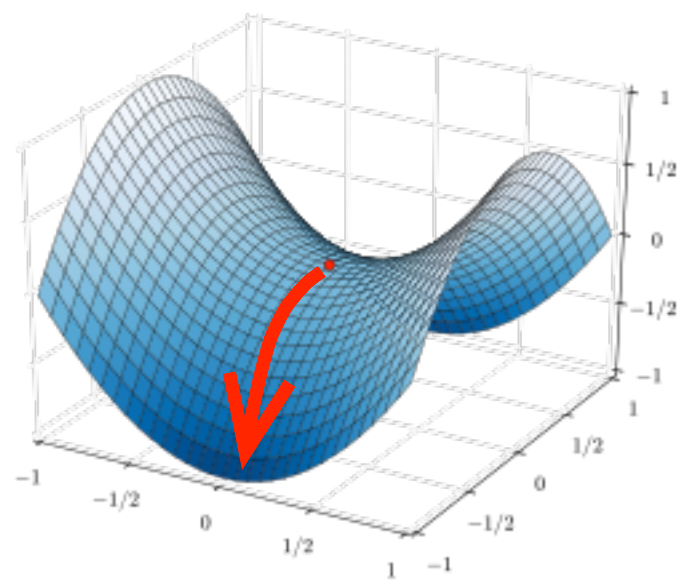
   (Perturbative and non-perturbative quantum corrections relevant)

   To evade no-go

Two problems:

2. Make sure critical point is really a local minimum!

<u>Problem</u>: For many scalar fields, saddle points are much more likely!



→ Tachyonic instabilities generic!

(No protection from SUSY in de Sitter)

More precisely: ∃ two types of tachyons:

1. "Statistical" tachyons

In a random potential with many scalars, the fraction of tachyon-free critical points is exponentially small

- Naively:

$$\mathbf{P(no\,tachyons)} \sim 2^{-\mathsf{N}_{\mathsf{scalars}}}$$

- More sophisticated estimates (in "random supergravity"):

Marsh, McAllister, Wrase (2011)
Chen, Shiu, Sumitomo, Tye (2011)
Sumitomo, Tye (2012)

$$\mathbf{P(no\ \ tachyon)} \sim \exp[-\mathbf{cN}^{1.3\ldots1.5}_{\mathsf{scalars}}]$$

More precisely: ∃ two types of tachyons:

1. "Statistical" tachyons

In a random potential with many scalars, the fraction of tachyon-free critical points is exponentially small

→ Extensive searches might give working examples

More precisely: ∃ two types of tachyons:

1. "Statistical" tachyons

In a random potential with many scalars, the fraction of tachyon-free critical points is exponentially small

→ Extensive searches might give working examples

2. "Structural" tachyons

In special classes of potentials, de Sitter tachyons might be unavoidable, even for few scalars

→ Don't waste your time on these models!

Example: Classical de Sitter vacua in IIA string theory

Example: Classical de Sitter vacua in IIA string theory

- Various known examples of de Sitter critical points

Early examples and related early work: Caviezel, Koerber, Körs, Lüst, Wrase, MZ (2008)
Flauger, Paban, Robbins, Wrase (2008)
Danielsson, Haque, Koerber, Shiu, Van Riet, Wrase (2011)
Silverstein (2007)
Haque, Shiu, Underwood, Van Riet (2008)
Danielsson, Haque, Shiu, Van Riet (2009)
Andriot, Goi, Minasian, Petrini (2010)
Dong, Horn, Silverstein, Torroba (2010)
Danielsson, Koerber, Van Riet (2010)

Example: Classical de Sitter vacua in IIA string theory

- Various known examples of de Sitter critical points

- All known examples have O(10) moduli and at least one tachyon

- All known examples are close to Minkowski vacua in parameter space (SUSY or no-scale)

See e.g. Danielsson, Dibitetto (2012)
Junghans (2016)

→ Are the observed tachyons statistical or structural?

I.e. is it worth searching for further examples?

This is part of the motivation for our work:

We investigate de Sitter vacua close to no-scale Minkowski vacua in 4D, N=1 supergravity

→ Are there structural tachyons, and if yes, under which conditions?

<u>A possible application</u>:

Are these conditions met in classical de Sitter vacua near no-scale Minkowski vacua?

If yes: Would identify the tachyon in at least a subset of the classical de Sitter vacua as structural

Rest of the talk

1. No-scale potentials
2. A structural tachyon
3. Ways to evade the tachyon
4. Application to classical de Sitter vacua
5. Summary and outlook

1. No-scale potentials

F-term potential in 4D, $\mathcal{N} = 1$ supergravity

$$\mathbf{V_F = e^K \left[K^{I\bar{J}}\ D_I W\ D_{\bar{J}} \overline{W} - 3|W|^2\right]}$$

$$\mathbf{K = K\left(\phi^I, \overline{\phi^I}\right)}$$ Kähler potential

$$\mathbf{W = W(\phi^I)}$$ Superpotential

$\mathbf{K^{I\bar{J}}} =$ Inverse of $\mathbf{K_{I\bar{J}} = \partial_I \partial_{\bar{J}} K \equiv \frac{\partial}{\partial \phi^I} \frac{\partial}{\partial \overline{\phi^J}} K}$

$$\mathbf{D_I W = \partial_I W + (\partial_I K) W}$$

F-term potential of no-scale type:

Ellis, Lahanas, Nanopoulos, Tamvakis (1984)

$$\{\phi^I\} = \{\phi^m, \phi^a\}$$

ϕ^m	No-scale fields
ϕ^a	Orthogonal fields

$$K = K_1\left(\phi^m, \overline{\phi^m}\right) + K_2\left(\phi^a, \overline{\phi^a}\right) \Leftrightarrow K_{m\bar{a}} = 0$$

$$W = W(\phi^a) \Leftrightarrow \partial_m W = 0$$

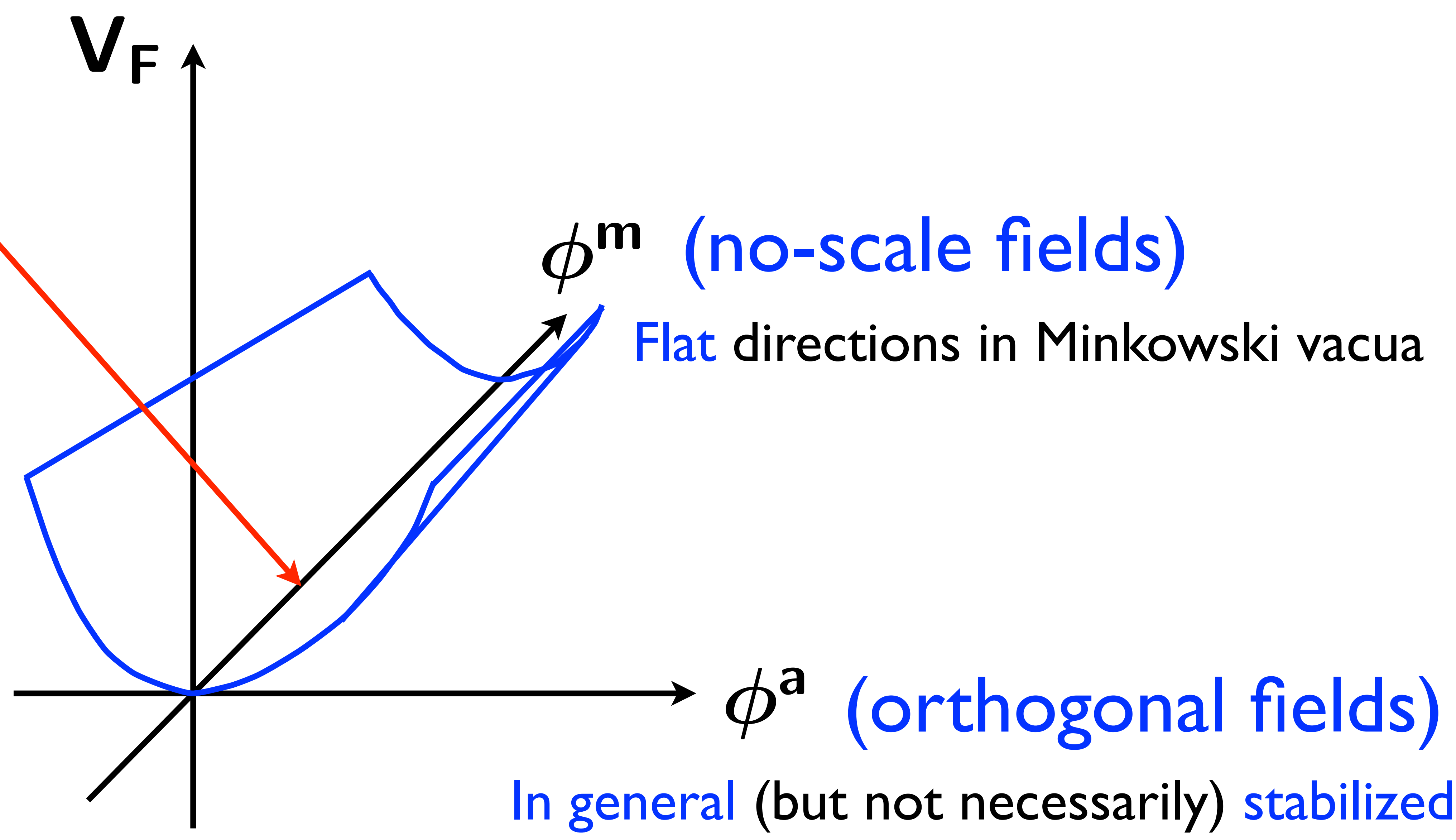
$$K^{m\bar{n}}\, K_m K_{\bar{n}} = 3$$

$$\Rightarrow \quad V_F = e^K \left[K^{a\bar{b}}\, D_a W\, D_{\bar{b}}\overline{W} + K^{m\bar{n}}\, \underbrace{D_m W}_{K_m W}\, \underbrace{D_{\bar{n}}\overline{W}}_{K_{\bar{n}}\overline{W}} - 3|W|^2\right]$$

$$= e^K \left[K^{a\bar{b}}\, D_a W\, D_{\bar{b}}\overline{W}\right] \geq 0$$

$$V_F = e^K \left[K^{a\bar{b}} \; D_a W \; D_{\bar{b}} \overline{W} \right] \geq 0$$

$$\langle D_a W \rangle = 0 \; \forall a \;\; \Leftrightarrow \;\; \langle V_F \rangle = 0 \;\; \& \;\; \langle \phi^m \rangle \text{ undetermined}$$



No-scale potentials are attractive because:

- Vanishing CC at arbitrary SUSY breaking scale

$$\Lambda = \langle V_F \rangle = 0$$

$$M^4_{SUSY} = \langle 3|W|^2 \rangle$$ (= model dependent, could be anything)

- A small deformation

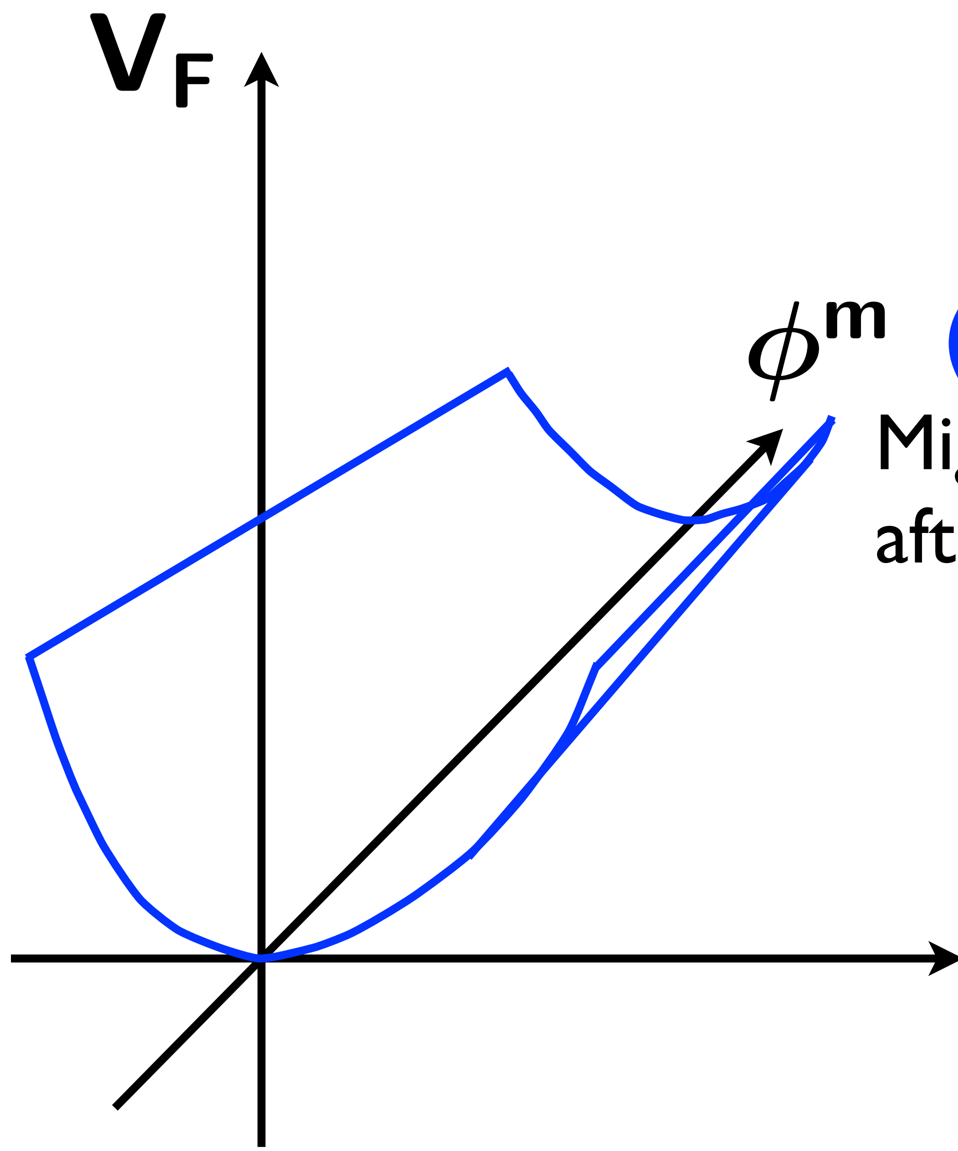
$$V_{no-scale} \to V_{no-scale} + \delta V$$

might generate

$$0 < \Lambda \ll M^4_{SUSY}$$

- For sufficiently small uplift deformation $\delta \mathbf{V}$ the stabilized ϕ^a remain stabilized at positive $\mathbf{M}^2$

- For sufficiently small uplift deformation $\delta \mathbf{V}$ the stabilized $\phi^{\mathbf{a}}$ remain stabilized at positive $\mathbf{M}^2$



$\phi^{\mathbf{m}}$ (no-scale fields)

Might become tachyonic after small deformation

$\phi^{\mathbf{a}}$ (orthogonal fields)

Remain stabilized after small deformation if stabilized in Minkowski vacuum

- For sufficiently small uplift deformation $\delta \mathbf{V}$ the stabilized $\phi^{\mathbf{a}}$ remain stabilized at positive $\mathbf{M}^2$

  $\Rightarrow$ Only the $\phi^{\mathbf{m}}$ might become tachyonic

  (or possible unstabilized $\phi^{\mathbf{a}}$)

$\Rightarrow$ Statistically favored over completely random potentials?

- No-scale potentials form basis of some interesting inflation models

- Semi-realistic string compactifications often lead to no-scale potentials at leading order

- Semi-realistic string compactifications often lead to no-scale potentials at leading order

E.g. IIB on Calabi-Yau orientifold with 3-form fluxes

$\phi^{\mathbf{a}}$ ↔ Complex structure moduli and dilaton
(stabilized classically by fluxes)

$\phi^{\mathbf{m}}$ ↔ Kähler moduli
(stabilized by quantum corrections ↔ $\delta \mathbf{V}$)

- Known classical de Sitter solutions occur near Minkowski solutions in parameter space

(SUSY or no-scale)

↑

Our work might help to understand the tachyons in these models

2. A structural tachyon

Our main theorem:

Consider $\mathsf{K}(\phi^m, \overline{\phi^m}, \phi^a, \overline{\phi^a})$, $\mathsf{W}(\phi^m, \phi^a; \lambda)$ such that

$$\mathsf{K} = -\ln[(\phi^m + \overline{\phi^m})(\phi^n + \overline{\phi^n})(\phi^l + \overline{\phi^l}) d_{mnl}] + \mathsf{K}_2(\phi^a + \overline{\phi^a})$$

$$\Rightarrow \mathsf{K}^{m\bar{n}}\, \mathsf{K}_m \mathsf{K}_{\bar{n}} = 3$$

$\lim_{\lambda \to 0} \mathsf{W}(\phi^m, \phi^a; \lambda) = \mathsf{W}(\phi^a)$ (I.e. $\lambda = 0 \leftrightarrow V_F = V_{no-scale}$)

with all ϕ^a stabilized at $\lambda = 0$

$\exists$ a de Sitter critical point for $\lambda \ll 1$ (i.e. close to the no-scale Minkowski vacua)

$$\mathsf{W}_{amn} \equiv \partial_a \partial_m \partial_n \mathsf{W} = \mathcal{O}(\lambda^2)$$

Then there always exist functions $\mathbf{Y_a}(\phi^{\mathbf{m}}, \phi^{\mathbf{b}})$ such that the complex field

$$\psi = \mathbf{K_m}\phi^{\mathbf{m}} + \boldsymbol{\lambda}\mathbf{Y_a}(\phi^{\mathbf{m}}, \phi^{\mathbf{b}})\phi^{\mathbf{a}}$$

contains a tachyon at the dS vacuum

Note: Ψ is in general not the sGoldstino

$$\mathbf{S} := \frac{\mathbf{D_I W}}{\mathbf{W}}\boldsymbol{\phi}^{\mathbf{I}} = \mathbf{K_m}\phi^{\mathbf{m}} + \underbrace{\frac{\partial_{\mathbf{m}}\mathbf{W}}{\mathbf{W}}}_{\mathcal{O}(\lambda)}\phi^{\mathbf{m}} + \underbrace{\frac{\mathbf{D_a W}}{\mathbf{W}}}_{\mathcal{O}(\lambda)}\phi^{\mathbf{a}}$$

It only aligns with it in the no-scale Minkowski limit:

$$\boldsymbol{\Psi}|_{\lambda=0} = \mathbf{K_m}\phi^{\mathbf{m}} = \mathbf{S}|_{\lambda=0}$$

In fact, one can easily construct dS examples where

E.g. Junghans (2016)

- Ψ is tachyonic
- S is stable

In fact, one can easily construct dS examples where

E.g. Junghans (2016)

- Ψ is tachyonic
- S is stable

Our theorem thus generalizes previous no-go theorems based on the sGoldstino direction

Brustein, de Alwis (2004)
Gomez-Reino, Scrucca (2006)
Gomez-Reino, Scrucca (2007)
Covi, Gomez-reino, Gross, Louis, Palma, Scrucca (2008)

3. Ways to evade the tachyon

Three ways to circumvent the no-go theorem within pure F-term models:

(i) Subleading corrections to the Kähler potential K

(E.g. α'^3 corrections in type IIB string theory)

Becker, Becker, Haack, Louis (2002)

(ii) Non-zero $\mathbf{W_{amn}} = \mathcal{O}(\lambda^1)$

(iii) At least one unstabilized $\phi^{\mathbf{a}}$ at no-scale Minkowski vacuum

Tricky

- Non-generic ⇒ Requires extra tuning freedom
- Yields extra statistical tachyon candidates

Recent discussion e.g. Achucarro, Ortiz, Sousa (2015)

4. Application to classical de Sitter vacua

Application to classical de Sitter vacua in IIA string theory:
Which of the three caveats are available?

Application to classical de Sitter vacua in IIA string theory: Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

Application to classical de Sitter vacua in IIA string theory: Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

Application to classical de Sitter vacua in IIA string theory:
Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

(ii) $\mathbf{W_{amn}} = \mathcal{O}(\lambda^1)$ only possible with non-geometric fluxes or instanton corrections

(i.e. not in classical dS vacua)

Application to classical de Sitter vacua in IIA string theory:
Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

(ii) $\mathbf{W_{amn}} = \mathcal{O}(\lambda^1)$ only possible with non-geometric fluxes or instanton corrections

(i.e. not in classical dS vacua)

Application to classical de Sitter vacua in IIA string theory: Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

(ii) $\mathbf{W_{amn}} = \mathcal{O}(\lambda^1)$ only possible with non-geometric fluxes or instanton corrections

(i.e. not in classical dS vacua)

(iii) Difficult to satisfy all constraints.
Does not work in STU-models

(Could not yet close all loop holes for general case)

Application to classical de Sitter vacua in IIA string theory: Which of the three caveats are available?

(i) Subleading corrections to K are by assumption negligible in classical de Sitter vacua

(ii) $W_{amn} = \mathcal{O}(\lambda^1)$ only possible with non-geometric fluxes or instanton corrections

(i.e. not in classical dS vacua)

(iii) Difficult to satisfy all constraints.
Does not work in STU-models

(Could not yet close all loop holes for general case)

At least one of the observed tachyons in classical IIA de Sitter solutions near no-scale Minkowski vacua might really be a structural tachyon.

5. Summary and outlook

Investigated de Sitter vacua near (a class of) no-scale Minkowski vacua

→ Have a tachyonic instability unless

- Subleading corrections to the Kähler potential are relevant and fulfill certain requirements

- $\mathbf{W_{amn}} = \mathcal{O}(\lambda^1)$

- At least one ϕ^{a} is unstabilized at the no-scale Minkowski vacuum

- More general potentials are assumed

Apart from a possible loop hole in the third (non-generic) case, none of these caveats are available for classical de Sitter vacua

The observed tachyons in classical de Sitter vacua may have structural rather than statistical reasons

(More work needed)

Further directions:

Generalize theorem to other situations (more general K, D-terms, nilpotent superfields, SUSY Minkowski vacua etc.)

Apply to phenomenologically interesting no-scale models (including inflation models)

Close loopholes for classical de Sitter vacua?

Useful also for other corners of the string landscape?
Understand the set of meta-stable de Sitter vacua