Large hierarchies from approximate *R* symmetries

Michael Ratz

Warsaw, 16.6.2009

Based on:
R. Kappl, H.P. Nilles, S. Ramos-Sánchez, M.R., K. Schmidt-Hoberg & P. Vaudrevange, Phys. Rev. Lett. **102**, 121602 (2009) (=arXiv:0812.2120)

Outline

1. Motivation
2. Hierarchically small vacuum expectation value of the perturbative superpotential due to an approximate R symmetry
3. Explicit string theory realization
4. Application to moduli stabilization

Motivation

Large hierarchies in Nature

- Observed hierarchy: $M_P/m_W \sim 10^{17}$

Large hierarchies in Nature

☞ Observed hierarchy: $M_P/m_W \sim 10^{17}$

Why?

Large hierarchies in Nature

- Observed hierarchy: $M_P/m_W \sim 10^{17}$

Why?

- Compelling answer: scale of supersymmetry breakdown set by dimensional transmutation

Witten (1981)

$$\Lambda \sim M_\mathrm{P} \exp\left(-b/g^2\right)$$

Large hierarchies in Nature

- Observed hierarchy: $M_P/m_W \sim 10^{17}$

Why?

- Compelling answer: scale of supersymmetry breakdown set by dimensional transmutation

Witten (1981)

$$\underbrace{\Lambda}_{\text{RG invariant scale}} \sim M_{\mathrm{P}} \exp\left(-\underbrace{b}_{\mathcal{O}(10)}/\underbrace{g^2}_{\mathcal{O}(1)\text{ coupling}}\right)$$

Large hierarchies in Nature

- Observed hierarchy: $M_P/m_W \sim 10^{17}$

Why?

- Compelling answer: scale of supersymmetry breakdown set by dimensional transmutation

Witten (1981)

$$\Lambda \sim M_\mathrm{P} \exp\left(-b/g^2\right)$$

- hierarchically small gravitino mass ('gaugino condensation')

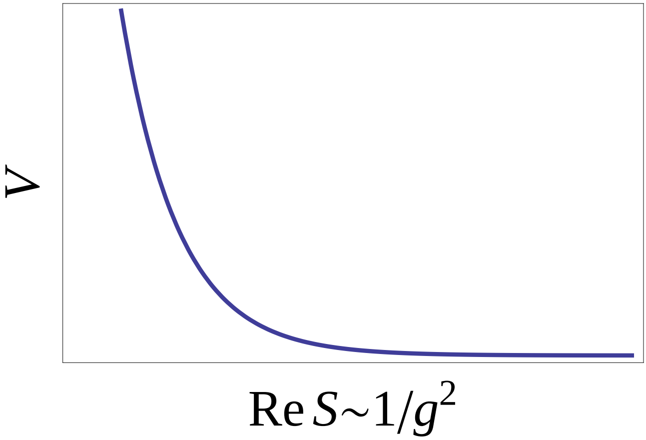
Nilles (1982)

$$m_W \sim m_{3/2} \sim \frac{\Lambda^3}{M_\mathrm{P}{}^2}$$

Problem with string theory realization

- ☞ **However**: embedding into string theory $\curvearrowright$ run-away problem

Dine, Seiberg (1985)



Moduli fixing and non-perturbative terms

There exist various possibilities to fix the gauge coupling/stabilize the dilaton:

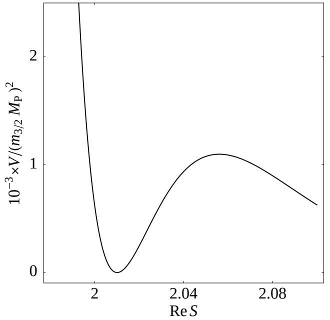
Moduli fixing and non-perturbative terms

There exist various possibilities to fix the gauge coupling/stabilize the dilaton:

- Race-track

  Krasnikov (1987)

use several gaugino condensates



Moduli fixing and non-perturbative terms

There exist various possibilities to fix the gauge coupling/stabilize the dilaton:

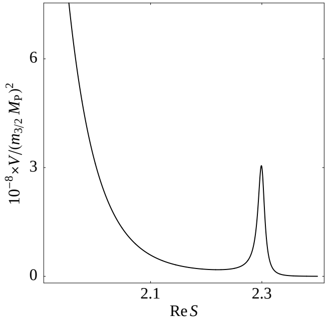
- Race-track
- Kähler stabilization

Casas (1996)

Binétruy, Gaillard & Wu (1996)

...

non-perturbative corrections to the Kähler potential



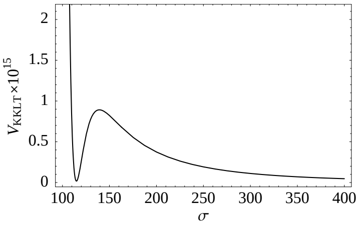
Moduli fixing and non-perturbative terms

There exist various possibilities to fix the gauge coupling/stabilize the dilaton:

- Race-track
- Kähler stabilization
- Flux compactification

e.g. Kachru, Kallosh, Linde & Trivedi (2003)

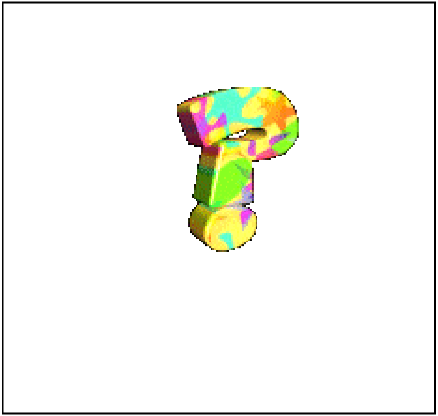
e.g. KKLT proposal



Moduli fixing and non-perturbative terms

There exist various possibilities to fix the gauge coupling/stabilize the dilaton:

- Race-track
- Kähler stabilization
- Flux compactification
- etc. . . .



Constant + exponential scheme

☞ KKLT type proposal: $\mathscr{W}_{\text{eff}} = \underbrace{c}_{\text{constant}} + \underbrace{A\,\mathrm{e}^{-a\,S}}_{\text{non-perturbative}}$

Constant + exponential scheme

- ☞ KKLT type proposal: $\mathscr{W}_{\mathrm{eff}} = c + A\,\mathrm{e}^{-a\,S}$
- ☞ Gravitino mass

$$m_{3/2} \sim |c|$$

Constant + exponential scheme

- ☞ KKLT type proposal: $\mathscr{W}_{\mathrm{eff}} = c + A\,\mathrm{e}^{-a\,S}$
- ☞ Gravitino mass

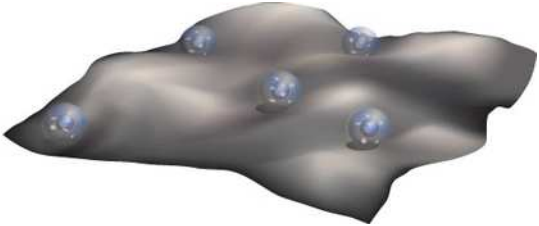
$$m_{3/2} \sim |c| \xrightarrow{m_{3/2} \overset{!}{\simeq} \mathrm{TeV}} |c| \sim 10^{-15}$$

Constant + exponential scheme

- KKLT type proposal: $\mathscr{W}_{\text{eff}} = c + A\,\mathrm{e}^{-a\,S}$
- Gravitino mass

$$m_{3/2} \sim |c| \quad \xrightarrow{m_{3/2} \overset{!}{\simeq} \text{TeV}} \quad |c| \sim 10^{-15}$$

- Philosophy of flux compactifications: many vacua, in some of them c might be small by accident



www.nature.com

Constant + exponential scheme

- KKLT type proposal: $\mathscr{W}_{\mathrm{eff}} = c + A\,\mathrm{e}^{-a\,S}$
- Gravitino mass

$$m_{3/2} \sim |c| \quad \xrightarrow{m_{3/2} \overset{!}{\simeq} \mathrm{TeV}} \quad |c| \sim 10^{-15}$$

- Philosophy of flux compactifications: many vacua, in some of them c might be small by accident
- Our proposal: hierarchically small expectation of the perturbative superpotential due to approximate $\mathrm{U}(1)_R$ symmetry

$$c \rightarrow \langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle \phi \rangle^N \quad \text{with} \quad N = \mathcal{O}(10)$$

typical VEV < 1

order of ~~U(1)~~$_R$

Small superpotential VEVs

from

approximate R symmetries

Hierarchically small $\langle\mathscr{W}\rangle$

Two ingredients:

1. in the presence of an exact $\mathrm{U}(1)_R$ symmetry

$$\boxed{\frac{\partial\mathscr{W}}{\partial\phi_i}=0} \curvearrowright \boxed{\langle\mathscr{W}\rangle=0}$$

Hierarchically small $\langle \mathscr{W} \rangle$

Two ingredients:

1. in the presence of an exact $\mathrm{U}(1)_R$ symmetry

$$\boxed{\frac{\partial \mathscr{W}}{\partial \phi_i} = 0} \curvearrowright \boxed{\langle \mathscr{W} \rangle = 0}$$

fields

superpotential

Hierarchically small $\langle \mathscr{W} \rangle$

Two ingredients:

1. in the presence of an exact $\mathrm{U}(1)_R$ symmetry

$$\boxed{\frac{\partial \mathscr{W}}{\partial \phi_i} = 0} \curvearrowright \boxed{\langle \mathscr{W} \rangle = 0}$$

2. for an approximate R symmetries

$$\boxed{\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N}$$

typical
field vev

order
of explicit
$\mathrm{U}(1)_R$ breaking
terms

$\langle\mathscr{W}\rangle = 0$ because of $\mathrm{U}(1)_R$ (I)

aim: show that

$$\boxed{\frac{\partial\mathscr{W}}{\partial\phi_i} = 0} \curvearrowright \boxed{\langle\mathscr{W}\rangle = 0}$$

$\langle\mathscr{W}\rangle = 0$ because of $\mathrm{U}(1)_R$ (I)

aim: show that

$$\boxed{\frac{\partial\mathscr{W}}{\partial\phi_i} = 0} \curvearrowright \boxed{\langle\mathscr{W}\rangle = 0}$$

Consider a superpotential

$$\mathscr{W} = \sum c_{n_1\cdots n_M}\phi_1^{n_1}\cdots\phi_M^{n_M}$$

with an exact R-symmetry

$$\mathscr{W} \to \mathrm{e}^{2\mathrm{i}\,\alpha}\,\mathscr{W}\,, \quad \phi_j \to \phi_j' = \mathrm{e}^{\mathrm{i}\,r_j\,\alpha}\,\phi_j$$

where each monomial in $\mathscr{W}$ has total R-charge 2

$\langle \mathscr{W} \rangle = 0$ because of $\mathrm{U}(1)_R$ (II)

Consider a field configuration $\langle \phi_i \rangle$ with

$$F_i = \frac{\partial \mathscr{W}}{\partial \phi_i} = 0 \quad \text{at } \phi_j = \langle \phi_j \rangle$$

Under an infinitesimal $\mathrm{U}(1)_R$ transformation, the superpotential transforms nontrivially

$$\mathscr{W}(\phi_j) \rightarrow \mathscr{W}(\phi_j') = \mathscr{W}(\phi_j) + \sum_i \frac{\partial \mathscr{W}}{\partial \phi_i} \Delta \phi_i$$

$\langle \mathscr{W} \rangle = 0$ because of $\mathrm{U}(1)_R$ (II)

Consider a field configuration $\langle \phi_i \rangle$ with

$$F_i = \frac{\partial \mathscr{W}}{\partial \phi_i} = 0 \quad \text{at } \phi_j = \langle \phi_j \rangle$$

Under an infinitesimal $\mathrm{U}(1)_R$ transformation, the superpotential transforms nontrivially

$$\mathscr{W}(\phi_j) \rightarrow \mathscr{W}(\phi_j') = \mathscr{W}(\phi_j) + \sum_i \cancel{\frac{\partial \mathscr{W}}{\partial \phi_i}} \Delta \phi_i$$

$\langle \mathscr{W} \rangle = 0$ because of $\mathrm{U}(1)_R$ (II)

Consider a field configuration $\langle \phi_i \rangle$ with

$$F_i = \frac{\partial \mathscr{W}}{\partial \phi_i} = 0 \quad \text{at } \phi_j = \langle \phi_j \rangle$$

Under an infinitesimal $\mathrm{U}(1)_R$ transformation, the superpotential transforms nontrivially

$$\mathscr{W}(\phi_j) \to \mathscr{W}(\phi_j') = \mathscr{W}(\phi_j) + \sum_i \cancel{\frac{\partial \mathscr{W}}{\partial \phi_i}} \Delta\phi_i \stackrel{!}{=} \mathrm{e}^{2\mathrm{i}\,\alpha}\,\mathscr{W}$$

This is only possible if $\langle \mathscr{W} \rangle = 0$!

bottom-line:

$$\boxed{\frac{\partial \mathscr{W}}{\partial \phi_i} = 0} \curvearrowright \boxed{\langle \mathscr{W} \rangle = 0}$$

Comments

1. Statement $\langle \mathscr{W} \rangle = 0$ holds regardless of whether $\mathrm{U}(1)_R$ is unbroken (where it is trivial) or broken

Comments

1. Statement $\langle \mathscr{W} \rangle = 0$ holds regardless of whether $\mathrm{U}(1)_R$ is unbroken (where it is trivial) or broken

2. Relation to Nelson-Seiberg theorem

Nelson & Seiberg (1994)

$$\left\{ \begin{array}{c} \text{setting without} \\ \text{supersymmetric} \\ \text{ground state} \end{array} \right\} \xrightarrow{\text{requires}} \mathrm{U}(1)_R \text{ symmetry}$$

Comments

1. Statement $\langle \mathscr{W} \rangle = 0$ holds regardless of whether $\mathrm{U}(1)_R$ is unbroken (where it is trivial) or broken

2. Relation to Nelson-Seiberg theorem

Nelson & Seiberg (1994)

$$\left\{ \begin{array}{c} \text{setting without} \\ \text{supersymmetric} \\ \text{ground state} \end{array} \right\} \begin{array}{c} \xrightarrow{\text{requires}} \\ \text{does not imply} \\ \not\longleftarrow \end{array} \mathrm{U}(1)_R \text{ symmetry}$$

Comments

1. Statement $\langle\mathscr{W}\rangle = 0$ holds regardless of whether $\mathrm{U}(1)_R$ is unbroken (where it is trivial) or broken

2. Relation to Nelson-Seiberg theorem

   Nelson & Seiberg (1994)

   $$\left\{\begin{array}{c}\text{setting without}\\ \text{supersymmetric}\\ \text{ground state}\end{array}\right\} \begin{array}{c}\xrightarrow{\text{requires}}\\[1em] \xleftarrow{\text{does not imply}}\end{array} \mathrm{U}(1)_R \text{ symmetry}$$

3. in local SUSY : $\dfrac{\partial\mathscr{W}}{\partial\phi_i} = 0$ and $\langle\mathscr{W}\rangle = 0$ imply $D_i\mathscr{W} = 0$

   (That is, a $\mathrm{U}(1)_R$ symmetry implies Minkowski solutions.)

Comments

1. Statement $\langle \mathscr{W} \rangle = 0$ holds regardless of whether $\mathrm{U}(1)_R$ is unbroken (where it is trivial) or broken

2. Relation to Nelson-Seiberg theorem

Nelson & Seiberg (1994)

$$\left\{ \begin{array}{c} \text{setting without} \\ \text{supersymmetric} \\ \text{ground state} \end{array} \right\} \begin{array}{c} \xrightarrow{\text{requires}} \\ \xleftarrow{\text{does not imply}} \end{array} \mathrm{U}(1)_R \text{ symmetry}$$

3. in local SUSY : $\dfrac{\partial \mathscr{W}}{\partial \phi_i} = 0$ and $\langle \mathscr{W} \rangle = 0$ imply $D_i \mathscr{W} = 0$

(That is, a $\mathrm{U}(1)_R$ symmetry implies Minkowski solutions.)

4. in 'no-scale' type settings

$$\boxed{\begin{array}{c} \text{solutions of} \\ \text{global SUSY} \\ F \text{ term eq.'s} \end{array}} = \boxed{\begin{array}{c} \text{stationary points} \\ \text{of supergravity} \\ \text{scalar potential} \end{array}}$$

Weinberg (1989)

Approximate R symmetries

☞ Consider now the case of an **approximate** R symmetry, i.e. explicit R symmetry breaking terms appear at order N in the fields ϕ_i

Approximate R symmetries

- Consider now the case of an **approximate** R symmetry, i.e. explicit R symmetry breaking terms appear at order N in the fields ϕ_i
- This allows us to avoid certain problems:
  - for a continuous $\mathrm{U}(1)_R$ symmetry we would have
    - a supersymmetric ground state with $\langle\mathscr{W}\rangle = 0$ and $\mathrm{U}(1)_R$ spontaneously broken
    - a problematic R-Goldstone boson

Approximate R symmetries

- Consider now the case of an **approximate** R symmetry, i.e. explicit R symmetry breaking terms appear at order N in the fields ϕ_i
- This allows us to avoid certain problems:
  - for a continuous $\mathrm{U}(1)_R$ symmetry we would have
    - a supersymmetric ground state with $\langle \mathscr{W} \rangle = 0$ and $\mathrm{U}(1)_R$ spontaneously broken
    - a problematic R-Goldstone boson
  - however, for an **approximate** $\mathrm{U}(1)_R$-symmetry one has
    - Goldstone-Boson massive and harmless
    - a non-trivial VEV of $\mathscr{W}$ at order N in ϕ VEVs

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N$$

Approximate R symmetries

- Consider now the case of an **approximate** R symmetry, i.e. explicit R symmetry breaking terms appear at order N in the fields ϕ_i

- This allows us to avoid certain problems:
  - for a continuous $\mathrm{U}(1)_R$ symmetry we would have
    - a supersymmetric ground state with $\langle \mathscr{W} \rangle = 0$ and $\mathrm{U}(1)_R$ spontaneously broken
    - a problematic R-Goldstone boson
  - however, for an **approximate** $\mathrm{U}(1)_R$-symmetry one has
    - Goldstone-Boson massive and harmless
    - a non-trivial VEV of $\mathscr{W}$ at order N in ϕ VEVs
$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N$$

- Such **approximate** $\mathrm{U}(1)_R$ symmetries can be a consequence of discrete $\mathbb{Z}_N^R$ symmetries

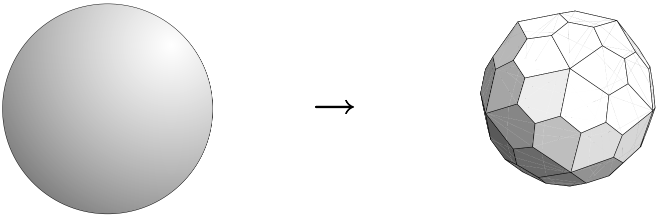
Explicit

string theory

realization

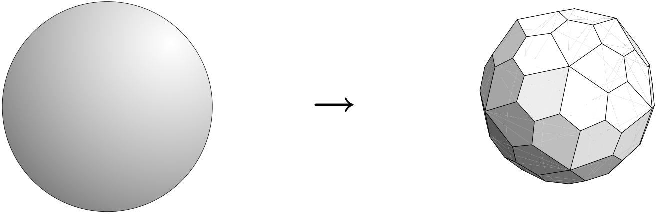
Origin of high-power discrete R-symmetries

☞ Discrete R symmetries arise as remnants of Lorentz symmetries of compact space



Origin of high-power discrete R-symmetries

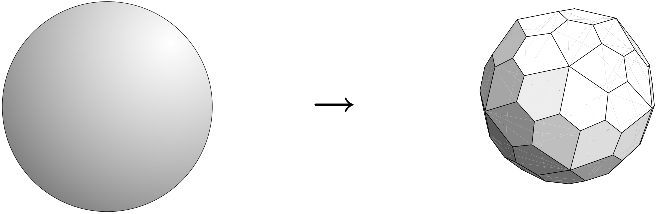
- Discrete R symmetries arise as remnants of Lorentz symmetries of compact space



- Orbifolds break $\mathrm{SO}(6) \simeq \mathrm{SU}(4)$ Lorentz symmetry of compact space to discrete subgroups

Origin of high-power discrete R-symmetries

- Discrete R symmetries arise as remnants of Lorentz symmetries of compact space



- Orbifolds break $\mathrm{SO}(6) \simeq \mathrm{SU}(4)$ Lorentz symmetry of compact space to discrete subgroups
- For example, in $\mathbb{Z}_6$-II orbifolds one has

$$G_R = [\mathbb{Z}_6 \times \mathbb{Z}_3 \times \mathbb{Z}_2]_R$$

see e.g. Araki, Kobayashi, Kubo, Ramos-Sánchez, M.R., Vaudrevange (2008)

Realization in heterotic mini-landscape

☞ Heterotic orbifolds appear ‘tailor-made’ for applying these ideas

Realization in heterotic mini-landscape

- Heterotic orbifolds appear ‘tailor-made’ for applying these ideas
- To be specific, focus on the heterotic mini-landscape = potentially realistic string derived models with nice features:
  - MSSM spectrum with one Higgs pair
  - potentially realistic flavor structure, see-saw, R parity, . . .
  - many standard model singlets s_i

cf. talks by R. Kappl, H.P. Nilles, S. Ramos-Sánchez

Realization in heterotic mini-landscape

☞ Heterotic orbifolds appear 'tailor-made' for applying these ideas

☞ To be specific, focus on the heterotic mini-landscape = potentially realistic string derived models with nice features:

- MSSM spectrum with one Higgs pair
- potentially realistic flavor structure, see-saw, R parity, . . .
- many standard model singlets s_i

cf. talks by R. Kappl, H.P. Nilles, S. Ramos-Sánchez

☞ In a large subset of the mini-landscape models, there is a correlation between the MSSM μ term and $\langle \mathscr{W} \rangle$

$$\mu \sim \langle \mathscr{W} \rangle$$

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- *R* symmetry breaking terms appear at order 9

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- R symmetry breaking terms appear at order 9
- We solve $D_a = 0$ as well as global $F_i = 0$ at order 9

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- R symmetry breaking terms appear at order 9
- We solve $D_a = 0$ as well as global $F_i = 0$ at order 9
- We specifically search for solutions $|s_i| < 1$, and find that they exist

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- R symmetry breaking terms appear at order 9
- We solve $D_a = 0$ as well as global $F_i = 0$ at order 9
- We specifically search for solutions $|s_i| < 1$, and find that they exist
- All fields acquire positive m^2
  (no flat directions; not destroyed by supergravity corrections)

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- R symmetry breaking terms appear at order 9
- We solve $D_a = 0$ as well as global $F_i = 0$ at order 9
- We specifically search for solutions $|s_i| < 1$, and find that they exist
- All fields acquire positive m^2
  (no flat directions; not destroyed by supergravity corrections)
- Superpotential VEV $\langle \mathscr{W} \rangle \sim \langle s_i \rangle^9 \ll 1$ (as expected)

Some details

- We studied one example (heterotic benchmark model IA) with 23 SM singlets s_i getting a VEV
- R symmetry breaking terms appear at order 9
- We solve $D_a = 0$ as well as global $F_i = 0$ at order 9
- We specifically search for solutions $|s_i| < 1$, and find that they exist
- All fields acquire positive m^2 (no flat directions; not destroyed by supergravity corrections)
- Superpotential VEV $\langle \mathscr{W} \rangle \sim \langle s_i \rangle^9 \ll 1$ (as expected)

bottom-line:

straightforward embedding in heterotic orbifolds

General picture

☞ The more fields are switched on, the lower N we obtain examples:

- benchmark model 1A with 23 fields $\curvearrowright$ $N = 9$
- model with 7 fields $\curvearrowright$ $N = 26$

General picture

☞ The more fields are switched on, the lower N we obtain examples:

- benchmark model 1A with 23 fields $\curvearrowright$ $N = 9$
- model with 7 fields $\curvearrowright$ $N = 26$

☞ Suppressed s_i in accord with scale set by Fayet-Iliopoulos term

General picture

- The more fields are switched on, the lower N we obtain examples:
  - benchmark model 1A with 23 fields $\curvearrowright$ $N = 9$
  - model with 7 fields $\curvearrowright$ $N = 26$
- Suppressed s_i in accord with scale set by Fayet-Iliopoulos term
- One approximate Goldstone mode η

$m_\eta \sim \langle \mathscr{W} \rangle / \langle s \rangle^2$ ...somewhat heavier than the gravitino

General picture

☞ The more fields are switched on, the lower N we obtain examples:

- benchmark model 1A with 23 fields $\curvearrowright$ $N = 9$
- model with 7 fields $\curvearrowright$ $N = 26$

☞ Suppressed s_i in accord with scale set by Fayet-Iliopoulos term

☞ One approximate Goldstone mode η

$m_\eta \sim \langle \mathscr{W} \rangle / \langle s \rangle^2$ ...somewhat heavier than the gravitino

☞ In most examples: all other s_i fields acquire masses $\gg m_\eta$ i.e. isolated points in s_i space with $F_i = D_a = 0$

General picture

- The more fields are switched on, the lower N we obtain examples:
  - benchmark model 1A with 23 fields $\curvearrowright$ $N = 9$
  - model with 7 fields $\curvearrowright$ $N = 26$
- Suppressed s_i in accord with scale set by Fayet-Iliopoulos term
- One approximate Goldstone mode η

  $m_\eta \sim \langle \mathscr{W} \rangle / \langle s \rangle^2$ ...somewhat heavier than the gravitino

- In most examples: all other s_i fields acquire masses $\gg m_\eta$ i.e. isolated points in s_i space with $F_i = D_a = 0$
- Minima survive supergravity corrections

Application: moduli stabilization

- ☞ Most direct application: fix the dilaton

Application: moduli stabilization

- Most direct application: fix the dilaton
- Effective superpotential

$$\mathscr{W}_{\mathrm{eff}} = \langle \mathscr{W} \rangle + A\,\mathrm{e}^{-a\,S} + \frac{1}{2} m_\eta\, \eta^2$$

approximate
R axion

perturbative
superpotential
$\sim 10^{-\mathcal{O}(10)}$

"gaugino
condensate"

Application: moduli stabilization

- Most direct application: fix the dilaton
- Effective superpotential

$$\mathscr{W}_{\mathrm{eff}} = \langle \mathscr{W} \rangle + A\,\mathrm{e}^{-a\,S} + \frac{1}{2} m_\eta\, \eta^2$$

- Dilaton adjusts to $\langle \mathscr{W} \rangle$

$$m_{3/2} \simeq \langle \mathscr{W}_{\mathrm{eff}} \rangle \sim \langle \mathscr{W} \rangle$$

Application: moduli stabilization

- Most direct application: fix the dilaton
- Effective superpotential

$$\mathscr{W}_{\mathrm{eff}} = \langle \mathscr{W} \rangle + A\,\mathrm{e}^{-a\,S} + \frac{1}{2} m_\eta\, \eta^2$$

- Dilaton adjusts to $\langle \mathscr{W} \rangle$

$$m_{3/2} \simeq \langle \mathscr{W}_{\mathrm{eff}} \rangle \sim \langle \mathscr{W} \rangle$$

bottom-line:

- dilaton fixed
- true origin of hierarchically small $m_{3/2}(\sim m_W)$: approximate R symmetry

Summary

&

outlook

Summary & outlook

☞ Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^{N} \quad \text{with } \langle \phi \rangle < 1$$

order of $\cancel{\mathrm{U}(1)_R}$

typical VEV

Summary & outlook

- Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^{N} \quad \text{with } \langle \phi \rangle < 1$$

- Such a suppressed superpotential VEV can play an important role in moduli fixing

Summary & outlook

- Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N \quad \text{with } \langle \phi \rangle < 1$$

- Such a suppressed superpotential VEV can play an important role in moduli fixing
- In this picture, the hierarchy between $m_W \sim m_{3/2}$ and M_P is consequence of an approximate symmetry

Summary & outlook

- Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N \quad \text{with } \langle \phi \rangle < 1$$

- Such a suppressed superpotential VEV can play an important role in moduli fixing
- In this picture, the hierarchy between $m_W \sim m_{3/2}$ and M_P is consequence of an approximate symmetry
- Still to do:
  - ‘uplifting’

Summary & outlook

- Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N \quad \text{with } \langle \phi \rangle < 1$$

- Such a suppressed superpotential VEV can play an important role in moduli fixing
- In this picture, the hierarchy between $m_W \sim m_{3/2}$ and M_P is consequence of an approximate symmetry
- Still to do:
  - `uplifting'
  - fixing of T and complex structure moduli (duality invariance; field-theoretic radion stabilization, ...)

Summary & outlook

- Approximate R symmetries can explain a suppressed expectation value of the perturbative superpotential

$$\langle \mathscr{W} \rangle \sim \langle \phi \rangle^N \quad \text{with } \langle \phi \rangle < 1$$

- Such a suppressed superpotential VEV can play an important role in moduli fixing
- In this picture, the hierarchy between $m_W \sim m_{3/2}$ and M_P is consequence of an approximate symmetry
- Still to do:
  - 'uplifting'
  - fixing of T and complex structure moduli (duality invariance; field-theoretic radion stabilization, ...)
  - unequivocal signatures of this scenario

Bordzo

Dziekuje!

‘Appendix’

Embedding into the MiniLandscape

- ☞ We analyzed a couple of models

Embedding into the MiniLandscape

- We analyzed a couple of models
- We find $\langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle s \rangle^N$ with $N = 9 \dots 26$

Embedding into the MiniLandscape

- We analyzed a couple of models
- We find $\langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle s \rangle^N$ with $N = 9 \dots 26$
- Assuming that the FI term sets the scale of the $\sim \langle s \rangle$ this leads to

$$\langle \mathscr{W} \rangle \;\sim\; \langle \mathscr{W}_{\mathrm{pert}} \rangle \;\sim\; 10^{-\mathcal{O}(10)}$$

Embedding into the MiniLandscape

- We analyzed a couple of models
- We find $\langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle s \rangle^N$ with $N = 9 \dots 26$
- Assuming that the FI term sets the scale of the $\sim \langle s \rangle$ this leads to

$$\langle \mathscr{W} \rangle \;\sim\; \langle \mathscr{W}_{\mathrm{pert}} \rangle \;\sim\; 10^{-\mathcal{O}(10)}$$

- **note**: the solutions of F-term equations are points in field space (no moduli in s_i-space)

Embedding into the MiniLandscape

- We analyzed a couple of models
- We find $\langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle s \rangle^N$ with $N = 9 \dots 26$
- Assuming that the FI term sets the scale of the $\sim \langle s \rangle$ this leads to

$$\langle \mathscr{W} \rangle \;\sim\; \langle \mathscr{W}_{\mathrm{pert}} \rangle \;\sim\; 10^{-\mathcal{O}(10)}$$

- **note**: the solutions of F-term equations are points in field space (no moduli in s_i-space)

➥ **application**: this

- generates a suppressed μ term

$$\mu \;\sim\; \langle \mathscr{W} \rangle \;\sim\; m_{3/2}$$

- fixes the gauge coupling / dilaton

Embedding into the MiniLandscape

- We analyzed a couple of models
- We find $\langle \mathscr{W}_{\mathrm{pert}} \rangle \sim \langle s \rangle^N$ with $N = 9 \ldots 26$
- Assuming that the FI term sets the scale of the $\sim \langle s \rangle$ this leads to

$$\langle \mathscr{W} \rangle \sim \langle \mathscr{W}_{\mathrm{pert}} \rangle \sim 10^{-\mathcal{O}(10)}$$

- **note**: the solutions of F-term equations are points in field space (no moduli in s_i-space)
- **application**: this
  - generates a suppressed μ term
    $$\mu \sim \langle \mathscr{W} \rangle \sim m_{3/2}$$
  - fixes the gauge coupling / dilaton
- **question**: is the dilaton fixed at realistic values?

Hidden sector strong dynamics

- Relation between $m_{3/2} \ll M_\mathrm{P}$ and the scale of hidden sector strong dynamics

$$G = G_\mathrm{SM} \times G_4$$

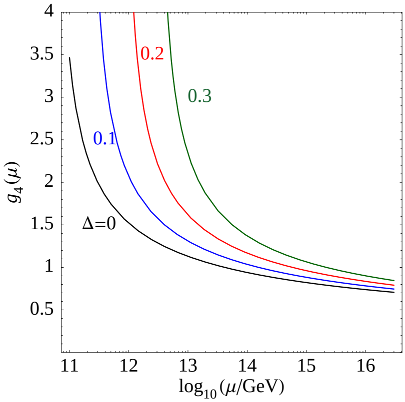
$$m_{3/2} \simeq \frac{\Lambda^3}{M_\mathrm{P}^2}$$

gravitino mass

scale of hidden sector strong dynamics

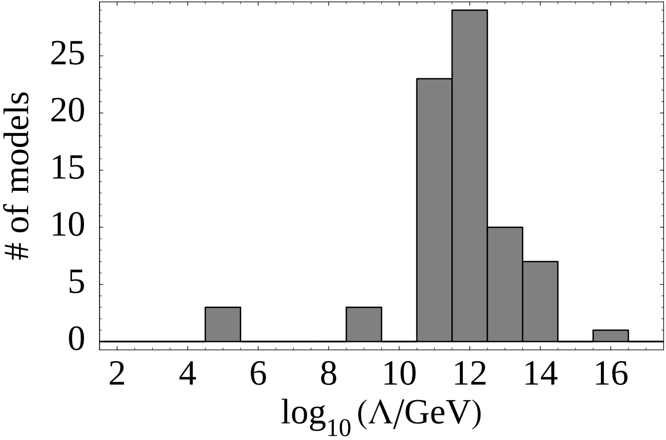
Hidden sector strong dynamics

- Relation between $m_{3/2} \ll M_{\mathrm{P}}$ and the scale of hidden sector strong dynamics
- We *estimate* the scale of hidden sector strong dynamics (i.e. calculate the β-function)



Properties of the hidden sector

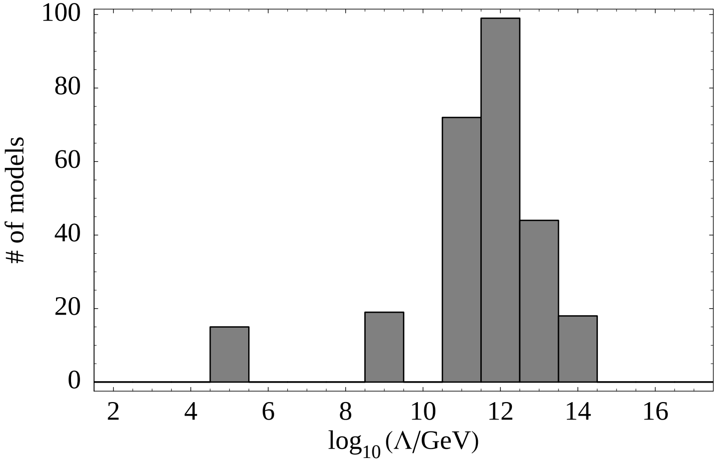
- Distribution of the (naive) scale of hidden sector strong dynamics



2 Wilson line case

Properties of the hidden sector

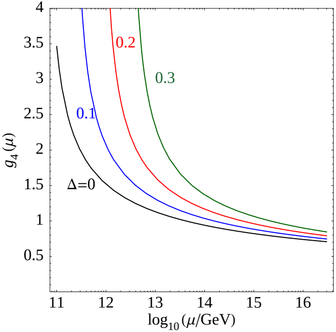
- Distribution of the (naive) scale of hidden sector strong dynamics



2+3 Wilson line case (heavy top)

Properties of the hidden sector

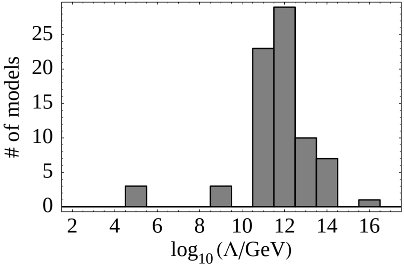
- Distribution of the (naive) scale of hidden sector strong dynamics



- **Note:** hidden sector usually **stronger** coupled

Properties of the hidden sector

- Distribution of the (naive) scale of hidden sector strong dynamics



- **Note:** hidden sector usually **stronger** coupled

bottom-line:

statistical preference for intermediate scale of condensation / a realistic gauge coupling