Higher Derivative Supergravity and Moduli Stabilization

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Based on [1505.03092] by DC, Jan Louis, Alexander Westphal

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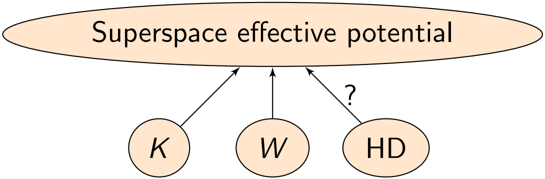
Introduction 1

- Objects of interest: Chiral superfields in $\mathcal{N} = 1$ in $d = 4$



- HD operators $\supset$ **ghost-free supersymmetrization** of $(\partial\phi)^4$

  [Cecotti, Ferrara, Girardello '87] [Khoury, Lehners, Ovrut '11] [Koehn, Lehners, Ovrut '12] ...

- Problem: HD theories imply existence of several on-shell theories

Goal 1: Understand these theories in the context of EFT

Introduction 2

- Corrections to scalar potential interesting for moduli stabilization
- Here: Type IIB CY3 flux compactifications
- Besides $V_{(\alpha')}$ [Becker, Becker, Haack, Louis '02] additional $(\alpha')^3$-corrections from 10D are expected that require HD as off-shell completion
- Typical scenarios involve W_{np} [Kachru, Kallosh, Linde, Trivedi '03], [Balasubramanian, Berglund, Conlon, Quevedo '05], but can vacua be found without including non-perturbative effects?

Goal 2: Derive HD from $(\alpha')^3$-corrections in type IIB flux-compactifications and study moduli stabilization

Global Case

- Simplest case: One Chiral Superfield [Khoury, Lehners, Ovrut '11]

$$\mathcal{O}_{hd} \sim \int d^4\theta \mathcal{T}\, D^\alpha \Phi D_\alpha \Phi \overline{D_{\dot\alpha}} \Phi^\dagger \overline{D^{\dot\alpha}} \Phi^\dagger$$
$$\sim \mathcal{T}\left[(\partial A)^2 (\partial \overline{A})^2 - 2|F|^2 |\partial A|^2 + |F|^4 + \text{fermionic}\right]$$

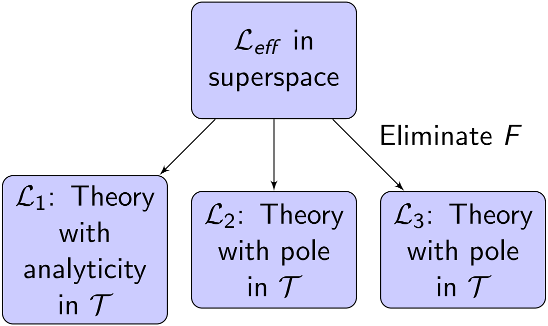
- Together with $K = \Phi\Phi^\dagger$ and W:

$$\overline{F} + \frac{\partial W}{\partial A} + 2\mathcal{T}\overline{F}\left(|F|^2 - |\partial A|^2\right) = 0$$

Result: **Three different on-shell theories**, new scalar potential, ...

- No ghosts

Discussion in EFT



- In EFT: $\mathcal{T} \sim M^{-4} \Longrightarrow$ Has to decouple as $M \to \infty$!
- **Only analytic theory obeys decoupling principle**
- Example: Full off-shell one-loop Wess-Zumino [Kuzenko, Tyler '14]
  $\rightarrow$ Non-analytic theories incapable of reproducing dynamics of non-local ("UV") Lagrangian

Coupling to Supergravity and Scalar Potential

- Make operator local and couple via chiral integral [Koehn, Lehners, Ovrut '12]
- Lowest order physical on-shell Lagrangian:

$$\mathcal{L}/\sqrt{-g} \supset -G_{A\bar{A}}(1+\Delta)|\partial A|^2 + \mathcal{T}(\partial A)^2(\partial \bar{A})^2 - V_0 - \delta V$$

- Correction to potential

$$\delta V \sim -\mathcal{T}(\mathrm{e}^K |D_A W|^2)^2 \sim |F_0|^4$$

Kähler Moduli Stabilization in Type IIB

- Setup: Type IIB CY3 orientifold flux compactification
- Fluxes stabilize complex structure moduli and dilaton
- Dynamics of Kähler moduli T determined via

$$K = -2\ln(\mathcal{V} + \hat{\xi}/2)\ , \quad W = W_0$$

- **Step 1:** Obtain additional $(\alpha')^3$-corrections
- **Step 2:** Can they stabilize the Kähler moduli instead of W_{np} ?

Higher-Derivatives from α'-Corrections 1

- $(\alpha')^3$-corrections to 10D action

$$S_{IIB} \supset (\alpha')^3 \int d^{10}x\sqrt{-g}[R^4 + R^3(G_3^2 + \dots) + R^2(G_3^4 + \dots) + \dots]$$

- $R^4 \xrightarrow{compactify} \hat{\xi}$-correction to kinetic terms [Becker, Becker, Haack, Louis '02] and $R^3 G_3^2$ partially accounts for $V_{(\alpha')}$
- $R^2 G_3^4$ induce δV, which cannot be described via corrections to K or W, but via HD instead
- Since explicit form of $R^2 G_3^4$ is unknown, compute four-derivative terms from R^4-correction

Strategy: Match four-derivatives to $|\mathcal{D}\Phi|^4$ and read off $\mathcal{T}$ to infer δV

Higher-Derivatives from α'-Corrections 2

- Simple case: One volume modulus $\mathcal{V}_s$, neglect fluxes

$$ds^2_{(10)} = \eta_{\mu\nu} dx^\mu dx^\nu + \underbrace{g_{mn}}_{=\mathcal{V}_s^{1/3} \tilde{g}_{mn}} dy^m dy^n$$

- Schematically: $R^4 \to (\partial \mathcal{V}_s)^4 R_{mnpq} R^{mnpq}$
- Result:

$$\mathcal{T} \sim (\alpha')^3 g_s^{-3/2} \int c_2 \wedge J$$

Scalar Potential

- Choose Kähler cone basis: $J = t^i \hat{D}_i$, $t^i \geq 0$ and

$$\Pi_i = \int c_2 \wedge \hat{D}_i \geq 0$$

- Scalar Potential for $\mathcal{V} \to \infty$

$$V \sim \hat{\xi}|W_0|^2\mathcal{V}^{-3} - \underbrace{\hat{\lambda}}_{?}|W_0|^4\Pi_i t^i \mathcal{V}^{-4} + \delta V_{(g_s)} + \ldots$$

- Example: “Swiss Cheese” Degree 18 hypersurface in $\mathbb{P}^4_{[1,1,1,6,9]}$: $\Pi_1 = 36, \Pi_5 = 102$

Existence of Minimum

If $\hat{\lambda} < 0$ then for any CY3 with $\chi > 0$ the potential has a non-susy AdS minimum, fixing all τ_i

$$\langle \tau_i \rangle \sim \Pi_i \ , \qquad \langle \mathcal{V} \rangle \sim |W_0|^3 (\hat{\lambda}/\hat{\xi})^{3/2}$$

- Here no non-perturbative effects are required to stabilize the τ_i, they are fixed by the topological information of c_2
- Gravitino mass $m_{3/2} \sim |W_0|^{-2}$, i.e. small $m_{3/2}$ and large $\mathcal{V}$ for large $|W_0|$
- "Orthogonal" to LVS as $\chi > 0$

Conclusions

- Superspace HD operators modify the effective potential and are relevant for moduli stabilization
- They can be made sense of within EFT
- Type IIB flux compactifications: Can be derived from leading order α' corrections in 10d
- For $\hat{\lambda} < 0$ imply a model-independent minimum, fixing **all** four-cycle volumes

Future Directions:

- Precise computation of $\hat{\lambda}$ necessary. This requires a systematic understanding of all off-shell HD in supergravity (Prerequisite: Analysis in global SUSY ✓)
- Flux/Warping is important [Grimm, Pugh, Weissenbacher '14],[Martucci '14], hence our approximation has to be checked! It will also be interesting to reduce additional terms in 10D

Thanks for your attention!