On the Effective Description of Large Volume Compactifications

Diego Gallego

Universidad Pedagógica y Tecnológica de Colombia
(UPTC)

Based on JHEP 1106 (2011) 087 [arXiv:1103.5469]

19th International Conference on Supersymmetry and Unification of Fundamental Interactions
Fermilab, August 29, 2011

Two-Step Moduli Stabilization

KKLT proposal for type-IIB [Kachru-Kallosh-Linde-Trivedi'03]

$$W = W_{flux}(U, S) + W_{np}(U, S, T), ,$$

gives enough dynamics for all moduli!

Too many moduli! $\mathcal{O}(50 - 100)$.

Two-Step Moduli Stabilization

KKLT proposal for type-IIB [Kachru-Kallosh-Linde-Trivedi'03]

$$W = W_{flux}(U, S) + W_{np}(U, S, T), ,$$

gives enough dynamics for all moduli!

Too many moduli! $\mathcal{O}(50 - 100)$.

1. Stabilize S and the U^i by W_{flux}.

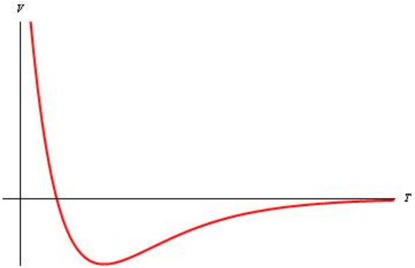
KKLT proposal for type-IIB [Kachru-Kallosh-Linde-Trivedi'03]

$$W = W_{flux}(U, S) + W_{np}(U, S, T), ,$$

gives enough dynamics for all moduli!

Too many moduli! $\mathcal{O}(50 - 100)$.

1. Stabilize S and the U^i by W_{flux}.
2. Stabilize T^i by W_{np}, regarding S and U^i frozen.
   At SUSY points $\langle F \rangle = 0$.



KKLT proposal for type-IIB [Kachru-Kallosh-Linde-Trivedi'03]

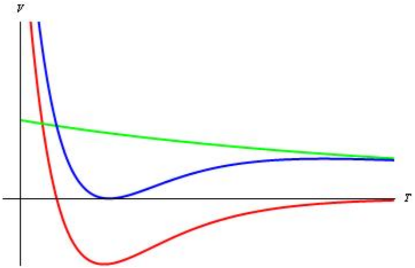
$$W = W_{flux}(U, S) + W_{np}(U, S, T), ,$$

gives enough dynamics for all moduli!

Too many moduli! $\mathcal{O}(50 - 100)$.

1. Stabilize S and the U^i by W_{flux}.
2. Stabilize T^i by W_{np}, regarding S and U^i frozen.
   At SUSY points $\langle F \rangle = 0$.
3. Break SUSY and get a vanishing Cosmological Constant using a decoupled sector.

$$\langle F^d \rangle \neq 0 \text{ and } \langle V \rangle = 0.$$



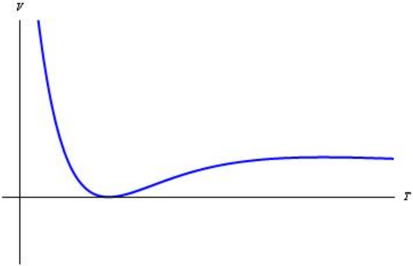
KKLT proposal for type-IIB [Kachru-Kallosh-Linde-Trivedi'03]

$$W = W_{flux}(U,S) + W_{np}(U,S,T), ,$$

gives enough dynamics for all moduli!

Too many moduli! $\mathcal{O}(50-100)$.

1. Stabilize S and the U^i by W_{flux}.
2. Stabilize T^i by W_{np}, regarding S and U^i frozen.
   At non-SUSY points $\langle F \rangle \neq 0$.



A system ruled by

$$W = W_0(H) + W_1(H, L).$$

Simplified

1. Motivated by the fact

$$W_0 \gg W_1 \,,$$

regard the H as fixed by W_0 at "SUSY" points regardless the L fields.

2. "Efective" simplified theory:

$$W_{sim}(L) = W_0(H_0) + W_1(H_0, L),$$

$$K_{sim}(L, \bar{L}) = K(H_0, \bar{H}_0, L, \bar{L}),$$

$$f_{AB,sim}(L) = f_{AB}(H_0, L),$$

Proper effective action

The H should be integrated out

$$\left.\frac{\partial \mathcal{L}}{\partial H}\right|_{H_0(L)} = 0 \,,$$

and the effective theory is

$$\mathcal{L}_{eff}(L) = \mathcal{L}(H_0(L), L)\,.$$

Usually is harder to proceed than with the original theory!

Is this procedure reliable?

[Choi-Falkowski-Nilles-Olechowski-Pokorski ’04, deAlwis ’05, Abe-Higaki-Kobayashi ’06, Blanco-Pillado–Kallosh–Linde ’06, Choi-Jeong-Okumora ’08 & ’09, Brizi-GomezReino-Scruca’09&10]

[Achucarro et al ’07-’08-’10]

Is this procedure reliable?

Can this be done with light fields?

[Choi-Falkowski-Nilles-Olechowski-Pokorski ’04, deAlwis ’05, Abe-Higaki-Kobayashi ’06, Blanco-Pillado–Kallosh–Linde ’06, Choi-Jeong-Okumora ’08 & ’09, Brizi-GomezReino-Scruca’09&10]

[Achucarro et al ’07-’08-’10]

A $\mathcal{N}=1$ SUGRA in $4D$, with

$$W(H^i, L^\alpha) = W_0(H^i) + \epsilon\, W_1(H^i, L^\alpha)\,, \quad \epsilon \ll 1\,.$$

Scalar potential without gauge interactions,

$$V = e^K \left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}D_N W - 3|W|^2\right) \stackrel{\epsilon\to 0}{\longrightarrow} e^K \left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}_0 D_N W_0 - 3|W_0|^2\right),$$

with i running over the H's and α over the L's

$$D_i W_0 = \partial_i W_0 + (\partial_i K) W_0\,, \quad D_\alpha W_0 = (\partial_\alpha K) W_0\,.$$

Decoupling of the Equation of Motion

A $\mathcal{N}=1$ SUGRA in $4D$, with

$$W(H^i, L^\alpha) = W_0(H^i) + \epsilon\, W_1(H^i, L^\alpha)\,, \quad \epsilon \ll 1\,.$$

Scalar potential without gauge interactions,

$$V = e^K\left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}D_N W - 3|W|^2\right) \overset{\epsilon\to 0}{\longrightarrow} e^K\left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}_0 D_N W_0 - 3|W_0|^2\right),$$

with i running over the H's and α over the L's

$$D_i W_0 = \partial_i W_0 + (\partial_i K)W_0\,, \quad D_\alpha W_0 = (\partial_\alpha K)W_0\,.$$

SUSY solution $F_{0,i} = D_i W_0 = 0$, not decoupled for generic K!

Decoupling of the Equation of Motion

A $\mathcal{N}=1$ SUGRA in $4D$, with

$$W(H^i, L^\alpha) = W_0(H^i) + \epsilon\, W_1(H^i, L^\alpha)\,, \quad \epsilon \ll 1\,.$$

Scalar potential without gauge interactions,

$$V = e^K\left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}D_N W - 3|W|^2\right) \stackrel{\epsilon\to 0}{\longrightarrow} e^K\left(K^{\bar{M}N}\overline{D}_{\bar{M}}\overline{W}_0 D_N W_0 - 3|W_0|^2\right),$$

with i running over the H's and α over the L's

$$D_i W_0 = \partial_i W_0 + (\partial_i K) W_0\,, \quad D_\alpha W_0 = (\partial_\alpha K) W_0\,.$$

SUSY solution $F_{0,i} = D_i W_0 = 0$, not decoupled for generic K!

Two ways for SUSY decoupling

1. A *tuning* in the W VEV: $\langle W_0\rangle \sim \mathcal{O}(\epsilon)$.
2. Factorizable structure: [Achucarro *et al.* '07-'08]

$$K = K_H(H,\bar{H}) + K_L(L,\bar{L}) + \mathcal{O}(\epsilon)\,.$$

Truncated equations of motion (e.o.m.)

[Brizi–Gómez-Reino-Scrucca '09]

The chiral superfield e.o.m.

$$\partial_H W = 0\,,$$

is exact at leading order $\frac{\partial^\mu}{m_H}$, $\frac{\psi^\alpha}{m_H^{3/2}}$, $\frac{F^\alpha}{m_H^2}$ and $\frac{F^\Phi}{m_H}$ with $m_H = \partial_H \partial_H W$.

Around $\partial_i W = 0$ with $\langle W_0 \rangle \sim \mathcal{O}(\epsilon)$ the corrections are negligible $\mathcal{O}(\epsilon^3)$!

For KKLT-like models

[DG-Serone'08-'09]

At the vacuum the superpotential is tiny ensuring a **mass hierarchy**. Then if

- The H multiplets are neutral.
- The lowest component is dictated by the scalar equation $\partial_H W_o = 0$.

W_{sim}, K_{sim} and $f_{AB,sim}$ are reliable at leading order in $\epsilon \sim m_L/m_H$.

The mass hierarchy explains the decoupling!

But in the natural case $\langle W \rangle \sim 1$...

- There is no superfield chiral e.o.m. in the market. [DG in preparation]
- **There is NO MASS HIERARCHY: all scales are naturally given by**

$$m_H \sim m_L \sim M_{SUSY} \sim \mathcal{O}(\langle e^{K/2}|W|\rangle) \, .$$

But in the natural case $\langle W \rangle \sim 1$...

- There is no superfield chiral e.o.m. in the market. [DG in preparation]
- **There is NO MASS HIERARCHY: all scales are naturally given by**

$$m_H \sim m_L \sim M_{SUSY} \sim \mathcal{O}(\langle e^{K/2} |W| \rangle) \,.$$

Large Volume Scenario (LVS) [Quevedo-Cambridge]

The CY volume, $\mathcal{V}$, is stabilized at exponentially large values.

No need for a tuning in W! $\quad \langle W \rangle \sim 1 \,.$

- SUSY broken at low energies $M_S \sim e^{-\mathcal{V}}$, [Balasubramanian et al. '05]
- Testable TeV spectra, Inflationary models, ect... [Quevedo-Cambridge, ect]

But

- All fields, including the Dilaton and Complex structure $W_o(H) = W_{CS}(S, U)$, get masses of the same order $\sim M_S$.

Pure moduli case

Type-IIB orientifold compactifications, S and U^i to be frozen.

$4D$, $\mathcal{N} = 1$ SUGRA with, $\mathcal{K}_{CS} = \mathcal{K}_{CS}(S, U)$, [Becker[2] et al. '02]

$$K = -2\log\left(\mathcal{V} + \xi\,(S + \overline{S})^{3/2}\right) + \mathcal{K}_{CS}\,, \quad W = W_{CS} + A\,e^{-at}\,.$$

In case $\mathcal{V} = \mathcal{V}(T, t's)$ very large the mixing is very small!

Type-IIB orientifold compactifications, S and U^i to be frozen.

$4D$, $\mathcal{N}=1$ SUGRA with, $\mathcal{K}_{CS}=\mathcal{K}_{CS}(S,U)$, [Becker[2] et al. '02]

$$K=-2\log\left(\mathcal{V}+\xi\,(S+\overline{S})^{3/2}\right)+\mathcal{K}_{CS}\,,\quad W=W_{CS}+A\,e^{-at}\,.$$

In case $\mathcal{V}=\mathcal{V}(T,t's)$ very large the mixing is very small!

Factorizable models

[Binetruy et al. '04]

Described by a Kähler invariant function $G=K+\log|W|^2$ such that

$$G(H,\bar{H},L,\bar{L})=G_H(H,\bar{H})+G_L(L,\bar{L})+\epsilon G_{mix}(H,\bar{H},L,\bar{H})\,,$$

with $\epsilon\ll 1$, H and L two field sectors. [Achucarro et al.'08, DG-Serone'08]
Mixing in the Lagrangian is suppressed and the sectors are decoupled.

Type-IIB orientifold compactifications, S and U^i to be frozen.

$4D$, $\mathcal{N} = 1$ SUGRA with, $\mathcal{K}_{CS} = \mathcal{K}_{CS}(S, U)$, [Becker[2] et al. '02]

$$K = -2\log\left(\mathcal{V} + \xi\,(S + \overline{S})^{3/2}\right) + \mathcal{K}_{CS}\,, \quad W = W_{CS} + A\,e^{-at}\,.$$

In case $\mathcal{V} = \mathcal{V}(T, t's)$ very large the mixing is very small!

Factorizable models

[Binetruy et al. '04]

Described by a Kähler invariant function $G = K + \log|W|^2$ such that

$$G(H,\bar{H},L,\bar{L}) = G_H(H,\bar{H}) + G_L(L,\bar{L}) + \epsilon G_{mix}(H,\bar{H},L,\bar{H})\,,$$

with $\epsilon \ll 1$, H and L two field sectors. [Achucarro et al.'08, DG-Serone'08]
Mixing in the Lagrangian is suppressed and the sectors are decoupled.

SAME ARGUMENTS APPLY FOR THE LVS!

The simplified version is reliable at leading order in $\epsilon \sim 1/\mathcal{V} \sim A\,e^{-at}$.

Matter multiplets [DG'11]

Necessary in any realistic scenario. They break factorizability!

$$K \supset Z(H, \bar{H}, L, \bar{L})|Q|^2 \,.$$

Necessary in any realistic scenario. They break factorizability!

$$K \supset Z(H, \bar{H}, L, \bar{L})|Q|^2 \,.$$

Generalized factorizable models

Such that, with $\phi^M = \{H, \mathcal{M}, Q\}$,

$$G(H, \bar{H}, L, \bar{L}) = G_H(H, \bar{H}) + G_{\mathcal{M}}(\mathcal{M}, \bar{\mathcal{M}}) + \epsilon G_{mix}(\phi, \bar{\phi}) \,.$$

Analyze from the scalar Lagrangian, [Kaku et al.'78, Kugo et al.'82]

$$\begin{aligned}\mathcal{L} =& G_{M\bar{M}} \partial_\mu \phi^M \partial^\mu \bar{\phi}^{\bar{M}} + G_M F^M \bar{U} + G_{\bar{M}} \bar{F}^{\bar{M}} U \\ &+ \left(G_{M\bar{M}} - \frac{1}{3} G_M G_{\bar{M}} \right) F^M F^{\bar{M}} - 3U\bar{U} - 3e^{\frac{G}{2}}(U + \bar{U}) \,,\end{aligned}$$

$\phi^M = (\phi^M, -F^M)$, and we fixed $\Phi = e^G(1, -U)$ the conf. compensator.
In order to hold manifestly SUSY we keep the auxiliary components!

Integrating out the $\mathcal{H}^i = \{H^i, -F^i\}$ multiplets

E.o.m. and effective Lagrangian

For F^i the usual s.t. $G_i = e^{-G/2} G_{i\bar{N}} F^{\bar{N}}$, for the lowest component

$$G_{ij} F^j \bar{U} + G_{ij\bar{k}} F^j \overline{F}^{\bar{k}} - \frac{1}{2}(U + 3\bar{U}) G_{i\bar{j}} \overline{F}^{\bar{j}} - \frac{1}{3} G_{ij} G_{\bar{N}} F^j \overline{F}^{\bar{N}} - \frac{1}{3} G_M G_{i\bar{j}} F^M \overline{F}^{\bar{j}} - G_{i\bar{j}} \partial^2 \bar{H}^{\bar{j}} + G_{i\bar{j}\bar{k}} \partial^\mu \bar{H}^{\bar{j}} \partial_\mu \bar{H}^{\bar{k}} = \mathcal{O}(\epsilon)\,.$$

No kinetic mixing!

E.o.m. and effective Lagrangian

For F^i the usual s.t. $G_i = e^{-G/2} G_{i\bar{N}} F^{\bar{N}}$, for the lowest component

$$G_{ij} F^j \bar{U} + G_{ij\bar{k}} F^j \overline{F}^{\bar{k}} - \frac{1}{2}(U + 3\bar{U}) G_{i\bar{j}} \overline{F}^{\bar{j}} - \frac{1}{3} G_{ij} G_{\bar{N}} F^j \overline{F}^{\bar{N}} \\ - \frac{1}{3} G_M G_{i\bar{j}} F^M \overline{F}^{\bar{j}} - G_{i\bar{j}} \partial^2 \bar{H}^{\bar{j}} + G_{i\bar{j}\bar{k}} \partial^\mu \bar{H}^{\bar{j}} \partial_\mu \bar{H}^{\bar{k}} = \mathcal{O}(\epsilon)\,.$$

Slow varying sol's, $F^i = \mathcal{O}(\epsilon) \Rightarrow G_i = \mathcal{O}(\epsilon)$. Then $H = H_o + \epsilon \Delta H(L)$:

$$\partial_i G_H = \left(\partial_i W_H + \partial_i K_H W_H\right) / \bar{W}_H \Big|_{H_0} = 0\,. \quad \text{leading F-flatness.}$$

H_o, L-independent!. Effective Lagrangian for the $L^\alpha = \{\mathcal{M}'s, Q's\}$

$$\begin{aligned} \mathcal{L}_{eff} &= G_{\alpha\bar{\beta}} \partial_\mu L^\alpha \partial_\mu \bar{L}^{\bar{\alpha}} + G_\alpha F^\alpha \bar{U} + G_{\bar{\alpha}} \overline{F}^{\bar{\alpha}} U \\ &\quad + \left(G_{\alpha\bar{\beta}} - G_\alpha G_{\bar{\beta}}/3\right) F^\alpha F^{\bar{\beta}} - 3U\bar{U} - 3e^{\frac{G}{2}}(U + \bar{U}) + \mathcal{O}(\epsilon^2)\,, \\ &= \mathcal{L}_{simp} + \mathcal{O}(\epsilon^2)\,. \end{aligned}$$

The simplified description is valid at leading order in ϵ!

Gauge isometries of the scalar manifold generated by holomorphic Killing vectors $\delta\phi^I = \Lambda^A X_A^M$, $A = 1, 2, \cdots dim(\mathcal{G})$.

- from gauge invariance $G_A = -iX_A^I G_I$ not all H^i field are fixed by the equations $G_i = 0$, unless neutral.
- if charged the H^i can be sourced back by the gauge fields.
- THE *H* MULTIPLETS SHOULD BE NEUTRAL!

Gauge isometries of the scalar manifold generated by holomorphic Killing vectors $\delta\phi^I = \Lambda^A X_A^M$, $A = 1, 2, \cdots dim(\mathcal{G})$.

- from gauge invariance $G_A = -iX_A^I G_I$ not all H^i field are fixed by the equations $G_i = 0$, unless neutral.
- if charged the H^i can be sourced back by the gauge fields.
- THE H MULTIPLETS SHOULD BE NEUTRAL!

The analysis is affected by

$$\mathcal{L} \supset G_A D^A + \frac{1}{2} h_{AB} D^A D^B \,,$$

$h_{AB} = Re(f_{AB})$ the gauge kin. functions and $V^A = \{V^A, D^A\}$ the vector superfields.
The e.o.m. for the lowest components is changed by

$$\partial_i \mathcal{L} \supset D^A D^B \partial_i h_{AB} + \text{suppressed.}$$

If SUSY is D-broken it back reacts in the H, i.e., $F^i \sim D^2$, no SUSY! Moreover H is L-dependent, not decoupled!

LVS with matter and gauge interactions

Suppressed wave functions are indeed realized ($\epsilon \sim 1/\mathcal{V}$) [Conlon et al. '06]

$$K \supset \frac{Z}{\mathcal{V}^n}|Q|^2\,, \quad n > 0 \;\text{ modular weight.}$$

LVS with matter and gauge interactions

Suppressed wave functions are indeed realized ($\epsilon \sim 1/\mathcal{V}$) [Conlon et al. '06]

$$K \supset \frac{Z}{\mathcal{V}^n}|Q|^2\,, \quad n > 0 \text{ modular weight.}$$

- **Not possible a general study**: at least three different suppression factors. Particular studies:
  - W independent of Q, [Cremades et al. '07]
  - Q dependen W, $N_c < N_f < 3N_c/2$ [Krippendorf-Quevedo '09]
  - Q dependen W, $N_f < N_c$.
- In type-IIB orientifolds with fluxes, [Lust et al. '04]

$$f = T + \kappa\, S\,,$$

$\kappa \sim 1$ so $\partial_H h = \mathcal{O}(1)$!

Nicely now the D's are suppressed the constrain is avoided!

The corrections to the simplified version are always suppressed by some powers of the volume!
Independent of the modular weights!

Conclusions

- Decoupling of light chiral fields, in a SUSY fashion, can be understood through the generalized factorizable models.
  - the frozen fields be neutral,
  - the frozen values be dictated by $\partial_i G_H = 0$.
  - the gauge kinetic function dependency be suppressed, i.e., $\partial_i h_{AB} \sim \epsilon$.
- In explicit realizations, LVS, the last condition is relaxed! The simplified description misses terms
  - suppressed by powers of $\mathcal{V}$, lead by modular weight indep. ones!
  - non-suppressed higher order operators.
- Outlook: The factorizables models, in general, present a context where regardless the lack of a scale hierarchy with the SUSY breaking scale the effective description is still SUSY.
  - How can be this understood from a superspace point of view?

Thank you!