Superpotential Desequestering in String Models

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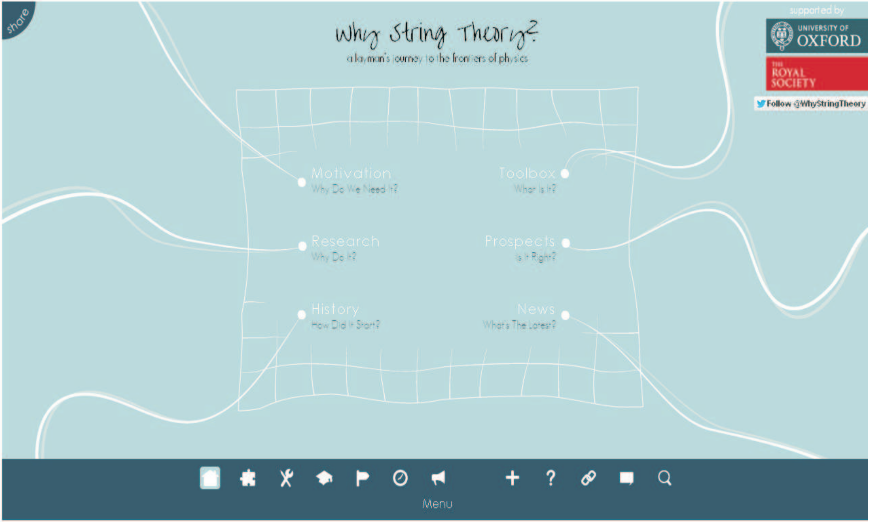
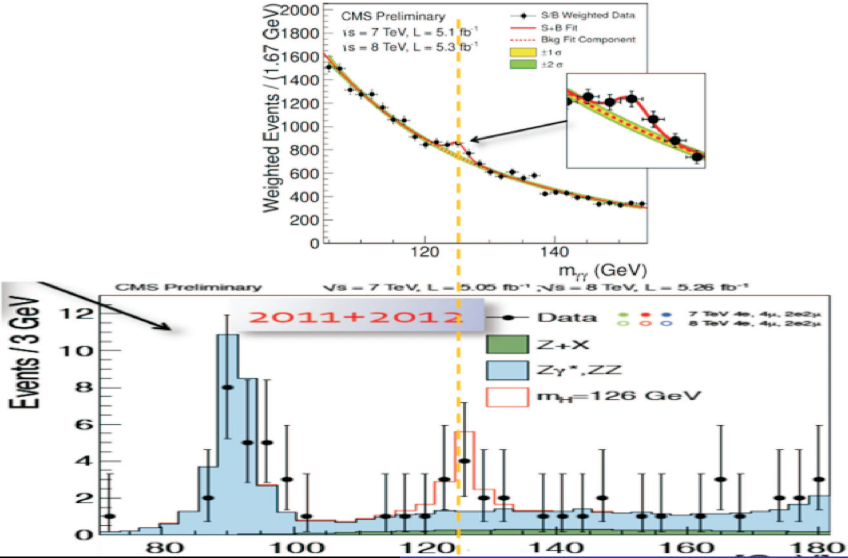
Based on 1207.1103 Berg JC Marsh Witkowski

WhyStringTheory.com: live last Tuesday



Higgs Discovery



Implications of Higgs Discovery

Higgs discovery

- Is of a fundamental scalar - the hierarchy problem is real.
- Is of a weakly coupled fundamental scalar - the hierarchy problem is real and technicolor is not the solution.
- Is of a weakly coupled fundamental scalar with $m_H = 125\text{GeV}$ - minimal supersymmetry is not the solution either.
- Is of a weakly coupled fundamental scalar with $m_H = 125\text{GeV}$ - some modification of supersymmetry, or fine-tuned supersymmetry is still conceivable.

Low energy supersymmetry is still the best solution to the hierarchy problem.

Problems of Low-Energy Supersymmetry

One of the biggest issues with low-energy supersymmetry is the flavour problem.

This arises from non-diagonal scalar masses or A-terms not aligned with Yukawa couplings.

It highly constrains the susy spectrum and must be solved in a realistic model.

Many string models of supersymmetry breaking have a leading order flavour universal structure.

Subleading corrections are dangerous.

Problems of Low-Energy Supersymmetry

This talk will focus on one source of dangerous terms.

$$
\begin{aligned}
A'_{\alpha\beta\gamma} &= e^{\hat{K}/2} F^m \Big[\hat{K}_m Y_{\alpha\beta\gamma} + \partial_m Y_{\alpha\beta\gamma} \\
&\quad - \Big((\partial_m \tilde{K}_{\alpha\bar{\rho}}) \tilde{K}^{\bar{\rho}\delta} Y_{\delta\beta\gamma} + (\alpha \leftrightarrow \beta) + (\alpha \leftrightarrow \gamma) \Big) \Big].
\end{aligned}
$$

A-terms not aligned with Yukawa couplings can generate dangerous CP violating couplings.

All terms other than first are in general unaligned.

We focus here on $\partial_m Y_{\alpha\beta\gamma}$ term - usually neglected as superpotential Yukawas independent of susy breaking field.

String Susy Breaking

In IIB models of moduli stabilisation (KKLT/LVS), Kähler moduli only appear non-perturbatively in the superpotential.

$$W = W_0 + A_s e^{-a_s T_s} + \dots$$

Kähler moduli are also responsible for susy breaking,

$$F^T \gg F^U, F^S$$

A-terms are induced by a term

$$W = Y_{ij}^{tree} H_u Q_L^i U_R^j + Y_{ij}^{new} H_u Q_L^i D_R^j e^{-a_s T_s}$$

Non-perturbative dependence of visible Yukawa couplings on distant condensing gauge groups.

String Susy Breaking

Why should we care?

Normally

$$e^{-a_s T_s} \sim \frac{m_{3/2}}{M_P} \ll 1$$

In this case

$$Y_{ij}^{new} H_u Q_L^i D_R^j e^{-a_s T_s}$$

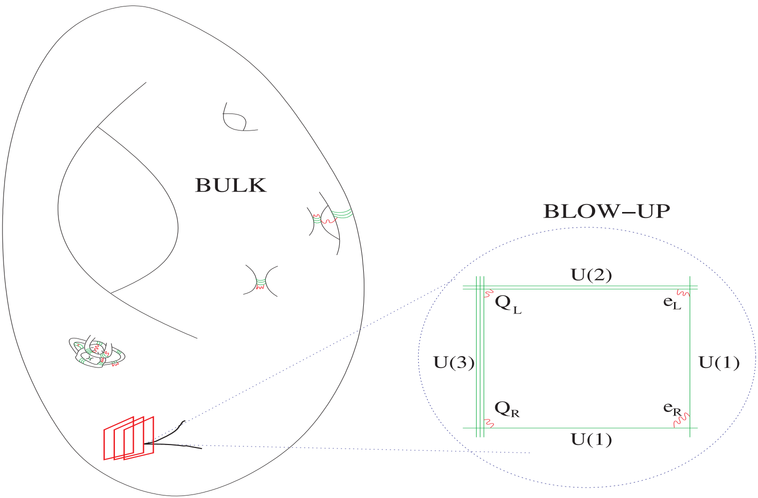
represents tiny corrections to SM Yukawa couplings.

If soft terms are generated at $\mathcal{O}(m_{3/2}) \sim 1\text{TeV}$,

$$\frac{m_{3/2}}{M_P} \sim 10^{-15}$$

and new A-terms are tiny and irrelevant corrections to leading order A-terms.

LARGE Volume Models



LARGE Volume Models

IIB flux compactifications have

$$\begin{aligned} K &= -2\ln\left(\mathcal{V}+\frac{\xi}{g_s^{3/2}}\right) - \ln\left(i\int \Omega\wedge\bar{\Omega}\right) - \ln\left(S+\bar{S}\right), \\ W &= \int G_3\wedge\Omega + \sum_i A_i e^{-a_i T_i}. \end{aligned}$$

Key ingredients for LVS are:

(1) the inclusion of stringy α' corrections to the Kähler potential
(2) nonperturbative instanton corrections in the superpotential.

LARGE Volume Models

The canonical example (the Calabi-Yau $\mathbb{P}^4_{[1,1,1,6,9]}$) has two moduli and a 'Swiss-cheese' structure:

$$\mathcal{V} = \left(\tau_b^{3/2} - \tau_s^{3/2}\right).$$

Computing the moduli scalar potential, we get for $\mathcal{V} \gg 1$,

$$V = \frac{\sqrt{\tau_s} a_s^2 |A_s|^2 e^{-2a_s\tau_s}}{\mathcal{V}} - \frac{a_s |A_s W| \tau_s e^{-a_s\tau_s}}{\mathcal{V}^2} + \frac{\xi |W|^2}{g_s^{3/2}\mathcal{V}^3}.$$

A minimum exists at

$$\mathcal{V} \sim |W_0| e^{a_s\tau_s}, \qquad \tau_s \sim \frac{\xi^{2/3}}{g_s}.$$

This minimum is non-supersymmetric AdS and at exponentially large volume.

LARGE Volume: Soft Terms

LVS (mostly) inherits its soft breaking structure from no-scale flux compactifications.

No-scale has many remarkable properties and cancellations.

1. Gaugino mass vanishes as f_a does not depend on volume modulus.
2. Anomaly-mediated gaugino mass also vanishes.

$$\begin{aligned} m_{1/2} &= -\frac{g^2}{16\pi^2}\Big[(3T_G - T_R)\, m_{3/2} - (T_G - T_R)\, K_i F^i \\ &\quad -\frac{2T_R}{d_R} F^i \partial_i \left(\ln \det Z\right) + 2T_G F^I \partial_I \ln\left(\frac{1}{g_0^2}\right)\Big] \\ &= 0. \end{aligned}$$

LARGE Volume: Soft Terms

No-scale has many remarkable properties and cancellations.

1. Leading order scalar mass vanishes.

$$m^2_{\tilde{Q}} = m^2_{3/2} - F^i F^{\bar{j}} \partial_i \partial_{\bar{j}} \ln \tilde{K} = 0.$$

2. In that the calculation exists, anomaly mediated scalar masses also vanish.

The upshot is that soft terms are suppressed significantly below the gravitino mass scale.

This violates the 'genericity' assumption $m_{soft} \sim m_{3/2}$.

With matter at singularities, soft terms appear to be suppressed to $\frac{M_P}{\mathcal{V}^2} \sim \frac{m^2_{3/2}}{M_P}$ - sequestered LARGE volume scenario.

Moduli Stabilisation: Sequestered LVS

The mass scales present are then (for $\mathcal{V} \sim 3 \times 10^7 l_s^6$)

Planck scale:	$M_P = 2.4 \times 10^{18}\,\text{GeV}.$
String scale:	$M_S \sim \frac{M_P}{\sqrt{\mathcal{V}}} \sim 10^{15}\,\text{GeV}.$
KK scale	$M_{KK} \sim \frac{M_P}{\mathcal{V}^{2/3}} \sim 10^{14}\,\text{GeV}.$
Gravitino mass	$m_{3/2} \sim \frac{M_P}{\mathcal{V}} \sim 10^{11}\,\text{GeV}.$
Small modulus	$m_{\tau_s} \sim m_{3/2} \ln\left(\frac{M_P}{m_{3/2}}\right) \sim 10^{12}\,\text{GeV}.$
Complex structure moduli	$m_U \sim m_{3/2} \sim 10^{11}\,\text{GeV}.$
Volume modulus	$m_{\tau_b} \sim \frac{M_P}{\mathcal{V}^{3/2}} \sim 4 \times 10^6\,\text{GeV}.$
Soft terms	$M_{soft} \sim \frac{M_P}{\mathcal{V}^2} \sim 10^3\,\text{GeV}.$

Moduli Stabilisation: Sequestered LVS

For sequestered case

$$M_{soft} \sim \frac{M_P}{\mathcal{V}^2} \sim 10^3 \text{GeV} \ll M_{3/2} \sim \frac{M_P}{\mathcal{V}} \sim 10^{11} \text{GeV}$$

'irrelevant' corrections

$$Y_{ij}^{new} H_u Q_L^i D_R^j e^{-a_s T_s}$$

become dangerous.

Estimate of 1012.1858 Berg Marsh McAllister Pajer is that such corrections are dangerous for $\mathcal{V} \gtrsim 10^5$.

We want to determine when they are present.

Calculation

Operator

$$Y_{ij}^{new} H_u Q_L^i D_R^j e^{-a_s T_s} \in W$$

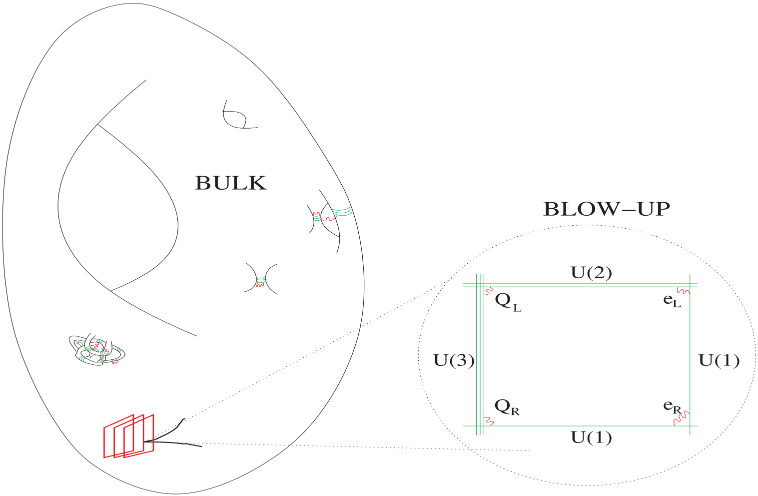
arises on hidden sector gaugino condensation if there is a term

$$f_{hidden} = T_s + Y_{ij}^{new} H_u Q_L^i D_R^j$$

Our aim is to determine dependence of hidden sector gauge kinetic function on visible sector matter fields.

Note: the string models studied do not involve actual condensation: they are simply visible and (distant) hidden sectors

Calculation



Calculation

We study the operator

$$\langle \mathrm{Tr}(\Phi_1 \Phi_2 \Phi_3)_{vis} \mathrm{Tr}(F_{\mu\nu} F^{\mu\nu})_{hidden} \rangle$$

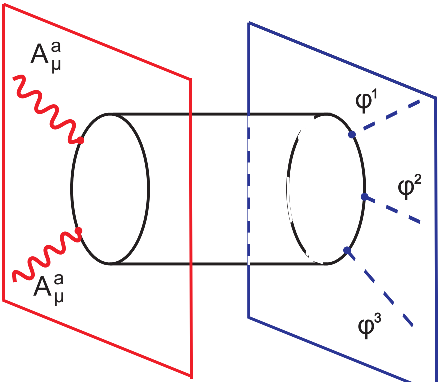
also and susy equivalently

$$\langle \mathrm{Tr}(\Phi_1 \psi_2 \psi_3)_{vis} \mathrm{Tr}(\lambda_a \lambda^a)_{hidden} \rangle$$

These both correspond to the appearance of $\Phi_1\Phi_2\Phi_3$ in the hidden sector gauge kinetic function.

Operators are double trace and are first generated at string one loop - annulus diagram.

The relevant string diagram is



Note: as a double trace operator only the annulus diagram contributes at string one loop level.

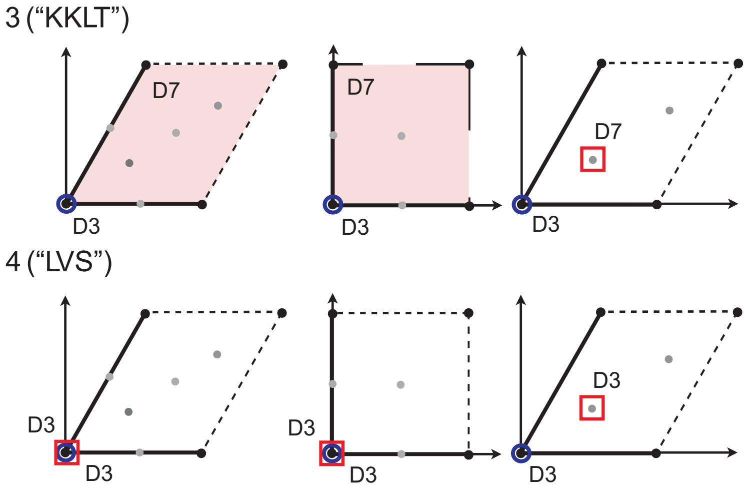
Calculation

How to model the visible and hidden sectors? We use different approaches for KKLT and LVS.

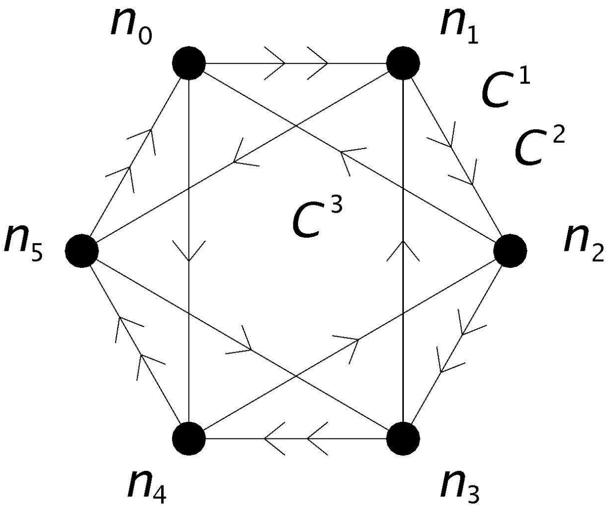
Alternative	Visible sector	Non-perturbative effects	Model
#1	Bulk D3	Bulk D7	not used
#2	Bulk D3	D3 at orbifold singularity	not used
#3	Fractional D3	Bulk D7	"KKLT"
#4	Fractional D3	D3 at orbifold singularity	"LVS"

Calculation

Pictorially:



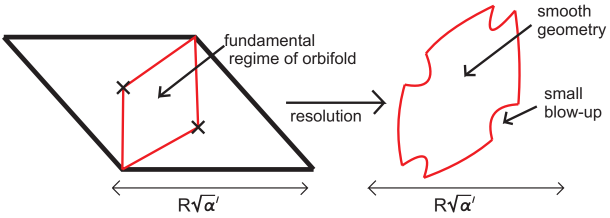
Visible Sector



D3 branes at $\mathbb{Z}_3, \mathbb{Z}_4, \mathbb{Z}_6$(shown) singularities: Yukawas are ϵ^{ijk}

Why Orbifolds?

Why should orbifolds approximate the smooth Calabi-Yau LVS geometry?



	Smooth LVS	Orbifold
Bulk Geometry	Almost Flat	Exactly Flat
'Visible Matter'	Singularity	Singularity
Hidden gauge group	Small cycle	Singularity
Behaviour of hidden gauge group	Condensing	None

Results

In 'KKLT' scenario

- Visible sector modelled as D3s at singularity
- Condensing group modelled as bulk D7 branes

In this case couplings

$$\Phi^3_{AB}\Phi^3_{BC}\Phi^3_{CA} \in f_{hidden}$$

are always generated and do NOT respect the tree-level flavour structure of ϵ^{ijk}.

This comes from the untwisted sector of the orbifold.

Results

In 'LVS'

- Visible sector modelled as D3s at singularity
- Condensing group modelled as D3s at singularity

In this case couplings

$$\Phi^3_{AB}\Phi^3_{BC}\Phi^3_{CA} \in f_{hidden}$$

are sometimes generated.

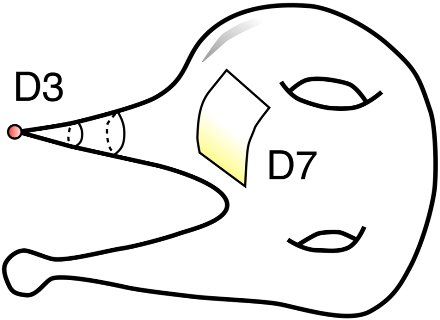
The untwisted sector is mutually $\mathcal{N} = 4$ and does not contribute.

The fully twisted ($\mathcal{N} = 1$) sector also vanishes.

The partially twisted ($\mathcal{N} = 2$) sector is nonzero only if both singularities share a 2-cycle

Pictorial Results

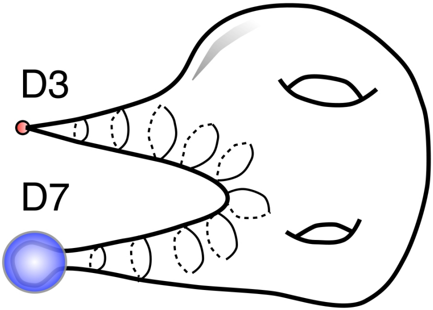
Fractional D3 always talks to bulk D7s



Untwisted sector of orbifold is $\mathcal{N} = 2$ supersymmetric and contributes

Pictorial Results

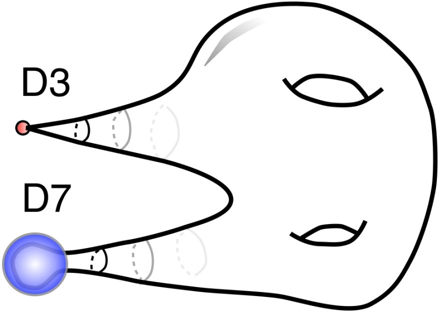
Fractional D3 talks to fractional D3 sharing a homologous 2-cycle



Homologous 2-cycle is $\mathcal{N} = 2$ sector of orbifold, $\mathcal{N} = 1$, $\mathcal{N} = 4$ sectors do not contribute

Pictorial Results

Fractional D3 does not talk to fractional D3 not sharing a homologous 2-cycle



No shared homologous 2-cycle - no shared orbifold $\mathcal{N} = 2$, $\mathcal{N} = 1$, $\mathcal{N} = 4$ sectors do not contribute

Conclusions

- It is possible to induce desequestering via induced couplings between visible and hidden sectors
- In LVS the conditions for such an induced coupling are quite restrictive
- They require the hidden and visible sector to be connected by a homologous 2-cycle
- We expect these geometric requirements to extend beyond the orbifold limit
- In KKLT these induced couplings always arise

Job Advert

- Two ERC-funded postdocs soon to be advertised at Oxford for October 2013
- One position 2+2 years
- One position 2 years
- Postdocs will be appointed within project area of ERC grant, 'Supersymmetry Breaking In String Theory'