Global model building with branes at singularities

Iñaki García-Etxebarria





Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)

in collaboration with F. Quevedo and R. Valandro arXiv:1512.06926 and with M. Cicoli, C. Mayrhofer, F. Quevedo, P. Shukla and R. Valandro arXiv:1706.06128

In string phenomenology we want to reproduce the observed physics. We are faced with numerous problems, here I want to focus on the breaking of supersymmetry:

- Nature is not supersymmetric, at least up to the energy scales we are currently able to probe.
- We observe a positive cosmological constant.

In string phenomenology we want to reproduce the observed physics. We are faced with numerous problems, here I want to focus on the breaking of supersymmetry:

- Nature is not supersymmetric, at least up to the energy scales we are currently able to probe.
- We observe a positive cosmological constant.

If we want to reproduce this lack of supersymmetry in string theory we have two options:

- Compactify higher-dimensional non-supersymmetric theories.
- Compactify higher-dimensional supersymmetric theories, adding some localized sectors breaking supersymmetry.

In string phenomenology we want to reproduce the observed physics. We are faced with numerous problems, here I want to focus on the breaking of supersymmetry:

- Nature is not supersymmetric, at least up to the energy scales we are currently able to probe.
- We observe a positive cosmological constant.

If we want to reproduce this lack of supersymmetry in string theory we have two options:

- Compactify higher-dimensional non-supersymmetric theories.
- Compactify higher-dimensional supersymmetric theories, adding some localized sectors breaking supersymmetry.



Starting with supersymmetric string configurations in high dimensions has some advantages

- Few starting options ($d \in \{10, 11\}$), related by duality. (Some degree of universality in the conclusions, and duality helps in analyzing models.)
- We can try to engineer models where susy breaking is a "small correction" to a susy computation, which is technically simpler.

There are many variations of this "almost susy" theme, here we focus on models in the KKLT class. [$\{2003\}$ Kachru, Kallosh, Linde, Trivedi]

A quick review of IIB/F-theory

We work in IIB string theory (and its generalization, F-theory).

At low energies, IIB string theory is a 10d supergravity theory preserving 32 supercharges in flat space. To get physics closer to the real world, we split the manifold as $\mathbb{R}^{1,3} \times X$, where X is a *Calabi-Yau threefold*.

If X is small enough, at low energies we see a 4d theory preserving 8 supercharges ($\mathcal{N} = 2$). The features of the four dimensional theory are determined by the choice of X.



- $\mathcal{N}=2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

- $\mathcal{N} = 2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

In order to solve these problems one typically (in the IIB context) uses combination of various ingredients:

- $\mathcal{N} = 2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

In order to solve these problems one typically (in the IIB context) uses combination of various ingredients:

✓ We add fluxes, branes and orientifolds (breaks $\mathcal{N} = 2 \rightarrow \mathcal{N} = 1$, adds chirality, fixes a subset of moduli).

- $\mathcal{N} = 2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

In order to solve these problems one typically (in the IIB context) uses combination of various ingredients:

- ✓ We add fluxes, branes and orientifolds (breaks $\mathcal{N} = 2 \rightarrow \mathcal{N} = 1$, adds chirality, fixes a subset of moduli).
- Son-perturbative effects fix the rest of the moduli.

- $\mathcal{N} = 2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

In order to solve these problems one typically (in the IIB context) uses combination of various ingredients:

- ✓ We add fluxes, branes and orientifolds (breaks $\mathcal{N} = 2 \rightarrow \mathcal{N} = 1$, adds chirality, fixes a subset of moduli).
- Son-perturbative effects fix the rest of the moduli.
- The Due to fluxes, some regions of X become strongly warped. Add anti-D3 branes there to break $\mathcal{N} = 1 \rightarrow \mathcal{N} = 0$ and lift to de Sitter.

- $\mathcal{N} = 2$ in 4d does not allow for chirality.
- No de Sitter vacua in this class. [{2000} Maldacena, Nuñez]
- Massless moduli. (Massless scalar fields in four dimensions.)

In order to solve these problems one typically (in the IIB context) uses combination of various ingredients:

- ✓ We add fluxes, branes and orientifolds (breaks $\mathcal{N} = 2 \rightarrow \mathcal{N} = 1$, adds chirality, fixes a subset of moduli).
- Son-perturbative effects fix the rest of the moduli.
- $^{\rm ISS}$ Due to fluxes, some regions of X become strongly warped. Add anti-D3 branes there to break $\mathcal{N}=1\to\mathcal{N}=0$ and lift to de Sitter.

(Also, not discussed in KKLT: we need to explicitly engineer the SM particle content somehow, lots of recent progress.)

Conclusions

Artist's impression of KKLT



There is a fair amount of controversy about the last step in the KKLT construction, discussed in [{2009} Bena, Graña, Halmagyi] and many follow-ups.

In a nutshell, for a large number of anti-D3 branes we can use supergravity techniques for analyzing the system, and such analysis tends to find either instabilities or unphysical looking singularities. Not completely clear what is going on, but all careful analyses keep finding problems.

There is a fair amount of controversy about the last step in the KKLT construction, discussed in [{2009} Bena, Graña, Halmagyi] and many follow-ups.

In a nutshell, for a large number of anti-D3 branes we can use supergravity techniques for analyzing the system, and such analysis tends to find either instabilities or unphysical looking singularities. Not completely clear what is going on, but all careful analyses keep finding problems.

In part due to these problems, recently the limit with one (or just a few) anti-D3 branes has been the focus of attention. In this case it seems like we can more reliably discuss the EFT on the anti-D3 stack. [{2014} Michel, Mintun, Polchinski, Puhm, Saad], [{2014} Kallosh, Wrase]. This configuration seems to enjoy enhanced stability properties.

There is a fair amount of controversy about the last step in the KKLT construction, discussed in [{2009} Bena, Graña, Halmagyi] and many follow-ups.

In a nutshell, for a large number of anti-D3 branes we can use supergravity techniques for analyzing the system, and such analysis tends to find either instabilities or unphysical looking singularities. Not completely clear what is going on, but all careful analyses keep finding problems.

In part due to these problems, recently the limit with one (or just a few) anti-D3 branes has been the focus of attention. In this case it seems like we can more reliably discuss the EFT on the anti-D3 stack. [{2014} Michel, Mintun, Polchinski, Puhm, Saad], [{2014} Kallosh, Wrase]. This configuration seems to enjoy enhanced stability properties. (But see [{2016} Bena, Blåbäck, Turton].)

There is a fair amount of controversy about the last step in the KKLT construction, discussed in [{2009} Bena, Graña, Halmagyi] and many follow-ups.

In a nutshell, for a large number of anti-D3 branes we can use supergravity techniques for analyzing the system, and such analysis tends to find either instabilities or unphysical looking singularities. Not completely clear what is going on, but all careful analyses keep finding problems.

In part due to these problems, recently the limit with one (or just a few) anti-D3 branes has been the focus of attention. In this case it seems like we can more reliably discuss the EFT on the anti-D3 stack. [{2014} Michel, Mintun, Polchinski, Puhm, Saad], [{2014} Kallosh, Wrase]. This configuration seems to enjoy enhanced stability properties. (But see [{2016} Bena, Blåbäck, Turton].)

Simplest case

At low energies, anti-D3+O3 is described by a **nilpotent Goldstino multiplet**.

What is a nilpotent Goldstino multiplet? [{1972} Volkov-Akulov]

A chiral multiplet X such that $X^2 = 0$. Expanding in components

$$X = X_0 + \psi\theta + F\theta\bar{\theta} \tag{1}$$

the constraint requires

$$X_0 \sim \psi \psi / F \tag{2}$$

so the bosonic component does not propagate (and $F \neq 0$).

What is a nilpotent Goldstino multiplet? [{1972} Volkov-Akulov]

A chiral multiplet X such that $X^2 = 0$. Expanding in components

$$X = X_0 + \psi\theta + F\theta\bar{\theta} \tag{1}$$

the constraint requires

$$X_0 \sim \psi \psi / F \tag{2}$$

so the bosonic component does not propagate (and $F \neq 0$).

For the purposes of this talk, this gives a controlled EFT description of the dynamics of a susy breaking sector in string theory.

Nilpotent Goldstinos on the $\overline{D3}$

Consider the theory on a $\overline{\rm D3}$ in flat space. It is just 4d U(1) ${\cal N}=4$ SYM.

Nilpotent Goldstinos on the $\overline{D3}$

Consider the theory on a $\overline{\text{D3}}$ in flat space. It is just 4d U(1) $\mathcal{N}=4$ SYM.

To reproduce the Volkov-Akulov action, with a single fermionic degree of freedom, we introduce (2, 1) fluxes and an O3 [{2000} Dudas, Mourad], ..., [{2014} Kallosh, Wrase], [{2014} Bergshoeff, Dasgupta, Kallosh, Van Proeyen, Wrase], [{2015} Kallosh, Quevedo, Uranga]

	$SO(6)_R$		Flux		O3		
A_{μ}	1	\rightarrow	1	\rightarrow	0	(2)	
λ^i_{lpha}	4	\rightarrow	1	\rightarrow	1	(3)	
Φ^I	6	\rightarrow	0	\rightarrow	0		

The basic idea for the local embedding

Orientifolding Klebanov-Strassler

A nice strategy for engineering this setup, introduced in [{2015} Kallosh, Quevedo, Uranga], is to find orientifolds of Klebanov-Strassler-like throats [{2000} Klebanov, Strassler]:

The confining theory on branes at singularities is known to (often) give rise to fluxed throats. We would like to identify some orientifold involution playing the role of the O3 plane in projecting out gauge bosons.

Towards global embeddings

Desiderata

- Isolated O3 planes.
- Simplest local geometry possible.

Towards global embeddings

Desiderata

- Isolated O3 planes.
- Simplest local geometry possible.

In [$\{2015\}$ Kallosh, Quevedo, Uranga] there are concrete examples

- **Conifold** with non-compact O7⁺ plane.
- More complicated singularities $(xy = z^3w^2)$ with O3 planes.
- Local geometry only, so 4d gravity is non-dynamical.

Towards global embeddings

Desiderata

- Isolated O3 planes.
- Simplest local geometry possible.

In [{2015} Kallosh, Quevedo, Uranga] there are concrete examples

- **Conifold** with non-compact O7⁺ plane.
- More complicated singularities $(xy = z^3w^2)$ with O3 planes.
- Local geometry only, so 4d gravity is non-dynamical.

In this talk

- We construct an orientifold of the conifold with O3 planes.
- We provide embeddings of the local setup into explicit models.

Finding a global embedding



Onwards to explicit de Sitter model building!



Review of the conifold

Defined by $\{f=0\} \in \mathbb{C}^4$ where

$$f = xy - zw = 0. (4)$$

This has a singularity at f = df = 0, i.e. at x = y = z = w = 0.

Topologically, the conifold is the real cone over $S^2 \times S^3$. We can define two one-parameter families of smooth spaces having the conifold as their singular limit by making the S^2 or S^3 finite size at the bottom of the throat.



Review of the conifold



D3 branes probing the conifold

The theory on D3 (possibly fractional) branes at the singularity was worked out by [{1998} Klebanov,Witten] and [{2000} Klebanov,Strassler]. It is a $\mathcal{N}=1$ theory defined by the quiver and superpotential



We are interested in a particular orientifold of the conifold theory. We start by describing the effect in the field theory, where it is manifested as a \mathbb{Z}_2 involution:



We are interested in a particular orientifold of the conifold theory. We start by describing the effect in the field theory, where it is manifested as a \mathbb{Z}_2 involution:



We are interested in a particular orientifold of the conifold theory. We start by describing the effect in the field theory, where it is manifested as a \mathbb{Z}_2 involution:



 $W = \varepsilon_{ij}\varepsilon_{lm} \operatorname{Tr} \left(A_i \gamma_{USp} A_l^t \gamma_{SO} A_j \gamma_{USp} A_m^t \gamma_{SO} \right)$

We are interested in a particular orientifold of the conifold theory. We start by describing the effect in the field theory, where it is manifested as a \mathbb{Z}_2 involution:



$$W = \varepsilon_{ij}\varepsilon_{lm} \operatorname{Tr} \left(A_i \gamma_{USp} A_l^t \gamma_{SO} A_j \gamma_{USp} A_m^t \gamma_{SO} \right)$$

(This involution was constructed in [{2001} Ahn,Nam,Sin], [{2001} Imai,Yokono], and classified in [{2007} Franco, Hanany, Krefl, Park, Uranga, Vegh] as a "line orientifold" of the conifold.)
 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusions

Geometric action

We can reproduce the action of the orientifold on the geometry by reading the action on a probe D3 brane. More precisely, the mesonic branch of the probe $U(1) \times U(1)$ theory is parameterized by the fields

$$x = A_1B_1$$
 ; $y = A_2B_2$; $z = A_1B_2$; $w = A_2B_1$

subject to the constraint xy - zw = 0.

Geometric action

We can reproduce the action of the orientifold on the geometry by reading the action on a probe D3 brane. More precisely, the mesonic branch of the probe $U(1)\times U(1)$ theory is parameterized by the fields

$$x = A_1B_1$$
 ; $y = A_2B_2$; $z = A_1B_2$; $w = A_2B_1$

subject to the constraint xy - zw = 0. By reading the action of the field theory orientifold on these fields [{2001} Imai, Yokono], [{2007} Franco, Hanany, Krefl, Park, Uranga, Vegh] we can identify the geometric action:

$$(x, y, z, w) \mapsto (y, x, -z, -w)$$
(5)

with fixed locus at

$$\{x - y = z = w = 0\} \cap \{xy - zw = 0\} = \{x = y = z = w = 0\}.$$
 (6)

So an isolated fixed point, good!

 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusion

The orientifold on the deformed picture

The deformed conifold (finite size S^3 at the bottom), appearing after confinement of the fractional branes [{2000} Klebanov Strassler], is given by

$$xy - zw = \sum_{i=1}^{4} z_i^2 = t$$
 (7)

with ISD flux and t determined by the scale of confinement in the field theory.

The orientifold on the deformed picture

The deformed conifold (finite size S^3 at the bottom), appearing after confinement of the fractional branes [{2000} Klebanov Strassler], is given by

$$xy - zw = \sum_{i=1}^{4} z_i^2 = t$$
(7)

with ISD flux and t determined by the scale of confinement in the field theory.

The orientifold action $(x,y,z,w) \to (y,x,-z,-w)$ leaves fixed the (two) points

$$\{x, x, 0, 0 | x^2 = t\}.$$
 (8)

These points can be seen to lie on the poles of the S^3 at the bottom of the conifold.



Three questions



- What happens to the resolved phase?
- Relatedly, how come we have an O3 keeping fractional branes invariant?
- For model building (computing tadpoles, in particular) we need a way to read the sign of the O3 planes at these two fixed points from data of the brane system before confinement.

Answer to the first two questions

If we look to the action of the orientifold on the $S^2\times S^3$ away from the origin, for a fixed point on the S^3 the involution acts as the (fixed-point free) orientation reversal map

$$\sigma \colon S^2 \to S^2 2 \tag{9}$$

so that $S^2/\sigma = \mathbb{RR}^2$.

Answer to the first two questions

If we look to the action of the orientifold on the $S^2\times S^3$ away from the origin, for a fixed point on the S^3 the involution acts as the (fixed-point free) orientation reversal map

$$\sigma \colon S^2 \to S^2 2 \tag{9}$$

so that $S^2/\sigma = \mathbb{RR}^2$.

So D5 branes wrapping the collapsing cycle get a (-1) from $(-1)^{F_L}\Omega$ and another (-1) from σ , so they survive the projection.

And relatedly, the volume of the S^2 at the bottom of the conifold gets projected out:

$$\int_{S^2} B + iJ \in \mathbb{R} \,. \tag{10}$$

Or, in the GLSM language, the orientifold acts as $\xi \rightarrow -\xi$.

 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusion

 00000000000
 0000000000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 000
 00

Reading the orientifold charges

O3 planes on the conifold: IIA perspective



Reading the orientifold charges

O3 planes on the conifold: IIA perspective



(This conclusion corrects [{2001} Ahn,Nam,Sin], [{2001} Imai,Yokono], and can be double checked by explicitly analysing probe dynamics.)
 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusions

One more puzzle

What happens if we choose opposite signs on the two fixed points?

I don't know the answer. This is not needed for our current purposes, but it seems interesting.

More generally, a classification of all orientifolds (or more generally, S-folds) of the conifold seems worthwhile.

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- (1) IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

From the first perspective, an O3 plane arises when IIB string theory lives on the (non-Calabi-Yau) $\mathbb{C}^3/\mathbb{Z}_2$ orbifold

$$\sigma \colon (x, y, z) \to (-x, -y, -z) \,. \tag{11}$$

Supersymmetry is restored if we put a non-trivial $SL(2,\mathbb{Z})$ bundle on this orbifold, such that as we go around the non-trivial one-cycle on $S^5/\mathbb{Z}_2 = \mathbb{RP}^5$ we act with $-1 \in SL(2,\mathbb{Z})$. (One can identify this element with $(-1)^{F_L}\Omega$ in the worldsheet language.)

Conclusions

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- 1 IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

In the second perspective the O3 plane is given by a fourfold $(\mathbb{C}^3 \times T^2)/\mathbb{Z}_2$ with four $\mathbb{C}^4/\mathbb{Z}_2$ terminal singularities.

Global embeddings (IIB)

Conclusions 000

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- ① IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

We combine both perspectives for constructing the embeddings.

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- **1** IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

We combine both perspectives for constructing the embeddings.

1 We take a IIB background which is locally a conifold.

Global embeddings (IIB)

Conclusions 000

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- ① IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

We combine both perspectives for constructing the embeddings.

- 1) We take a IIB background which is locally a conifold.
- 2 We quotient it adequately, so that it has $\mathbb{C}^3/\mathbb{Z}_2$ singularities at the right places.

Conclusions 000

F-theory embedding: the isolated O3 plane

Two useful definitions for F-theory:

- ① IIB with a non-trivial dilaton. (More generally, a non-trivial $SL(2,\mathbb{Z})$ bundle on the IIB spacetime.)
- 2 The vanishing fiber limit for M-theory on a Calabi-Yau torus fibration.

We combine both perspectives for constructing the embeddings.

- 1) We take a IIB background which is locally a conifold.
- 2 We quotient it adequately, so that it has $\mathbb{C}^3/\mathbb{Z}_2$ singularities at the right places.
- 3 We construct an elliptically fibered Calabi-Yau fourfold over this base. SUSY (the CY_4 condition) then imposes that we are taking the $(-1)^{F_L}\Omega$ involution locally, so we do have an O3.

It is easy to find examples: all we need is a IIB background ${\cal B}$ (even with varying dilaton, so an arbitrary F-theory base) with

- The capacity to develop a conifold in the base somewhere in moduli space.
- An involution σ compatible with the local involution we want. We then simply have to construct the elliptic Calabi-Yau fourfold fibration over \mathcal{B}/σ .

It is easy to find examples: all we need is a IIB background ${\cal B}$ (even with varying dilaton, so an arbitrary F-theory base) with

- The capacity to develop a conifold in the base somewhere in moduli space.
- An involution σ compatible with the local involution we want. We then simply have to construct the elliptic Calabi-Yau fourfold fibration over \mathcal{B}/σ .

An example, from [{2001} Giddings, Kachru, Polchinski]:

$$\sum_{i=1}^{4} (z_5^2 + z_i^2) z_i^2 - t^2 z_5^4 = 0$$
(11)

inside \mathbb{P}^4 . For t = 0 there is a conifold singularity close to $z_i = (0, 0, 0, 0, 1)$. The parameter t gives a deformation of the conifold, and $(z_1, z_2, z_3, z_4, z_5) \mapsto (-z_1, z_2, -z_3, -z_4, z_5)$ induces the right local structure.

Nilpotent Goldstino Retrofitting



IIB embedding: basic strategy

Sometimes we can follow a different strategy, and **retrofit** an existing model already having O3 planes. In this case we require

- A locus in moduli space where two orientifolds come together.
- That the local structure is that of the orientifolded conifold we constructed.

Then, by running our previous analysis backwards we can add a Goldstino+flux sector by going to the singular locus, adding condensing fractional branes in the right amount, and then the tadpole-free metastable sector on top.

IIB embedding example

In fact, we identified a state-of-the-art model with the right ingredients: [{2007} Diaconescu, Donagi, Florea], [{2012} Cicoli,Krippendorf,Mayrhofer,Quevedo,Valandro].



- Chiral matter.
- Moduli stabilization.
- Tadpole-free.
- Nilpotent Goldstino sector.

 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusions

Conclusions

- We constructed various string backgrounds with
 - 🖙 a robust uplift mechanism,
 - a chiral sector,
 - and moduli stabilization.
- The key point was realizing the uplift sector in a generic enough setting; the conifold fits the bill perfectly (after understanding some peculiar facts of the orientifolded case).
- We provided search strategies in F-theory and IIB, giving explicit, phenomenologically interesting, examples.

 Intro
 O3 planes on the conifold
 Global embeddings (F-theory)
 Global embeddings (IIB)
 Conclusions

Conclusions

- We constructed various string backgrounds with
 - 🖙 a robust uplift mechanism,
 - a chiral sector,
 - and moduli stabilization.
- The key point was realizing the uplift sector in a generic enough setting; the conifold fits the bill perfectly (after understanding some peculiar facts of the orientifolded case).
- We provided search strategies in F-theory and IIB, giving explicit, phenomenologically interesting, examples.
- **Open question:** Field theory description of the metastable vacuum? Maybe doable in our setting?

An advertisement

Here I have focused on the nilpotent Goldstino as the uplift mechanisms. Recently we constructed a global model, based instead on the T-brane uplift idea in [$\{2015\}$ Cicoli, Quevedo, Valandro], with

- Chiral matter (toy version, SU(5)-GUT inspired).
- Closed string moduli stabilization on a dS vaccum.
- Allows for inflation.

The gory technical details can be found in [{2017} Cicoli, I.G.-E., Mayrhofer, Quevedo, Shukla, Valandro].

The fine print

Before claiming victory, we need better techniques for

- Computing Kähler potentials.
- Computing non-perturbative superpotentials.
- Computing soft terms (in particular for matter).

Supplementary material

A metastable decay channel

In order to engineer local symmetry breaking, we choose to put a stuck $\overline{D3}$ on one O3⁻, and a stuck D3 on the other O3⁻. In this way, the total charge is as if there were no stuck D3 branes.

There is then a decay channel (reminiscent of [{2001} Kachru, Pearson, Verlinde]), visible using the [{2000} Hyakutake,Imamura,Sugimoto] description of the stuck D3 as a D5 on $\mathbb{RP}^2 \in H_2(X, \widetilde{\mathbb{Z}})$



May be more tractable than brane-flux annihilation.

It is slightly easier, for technical reasons, to deal with a blown-up version of this space along $z_2 = z_5 = 0$ (this does not intersect the conifold point at $z_1 = z_2 = z_3 = z_4 = 0$)

with SRI $\{z_1z_3z_4\lambda,z_2z_5\}.$ The new equation describing the Calabi-Yau is

$$\hat{P} = \sum_{i=1,3,4} (z_5^2 \lambda^2 + z_i^2) z_i^2 + (z_5^2 + z_2^2) z_2^2 \lambda^4 - t^2 z_5^4 \lambda^4 = 0.$$
(13)

In this representation, the involution of interest is $\lambda \rightarrow -\lambda$.

The quotient $\mathcal{B}=X/\mathbb{Z}_2$ is then simply given by introducing $\Lambda=\lambda^2$

with SR-ideal $\{z_1z_3z_4\Lambda,z_2z_5\}.$ The equation describing ${\cal B}$ is then

$$\mathsf{P} = \sum_{i=1,3,4} (z_5^2 \Lambda + z_i^2) z_i^2 + (z_5^2 + z_2^2) z_2^2 \Lambda^2 - t^2 z_5^4 \Lambda^2 = 0.$$
 (15)

On a neighborhood of the original conifold we have

$$\widetilde{\mathsf{P}} = \sum_{i=1,3,4} (1+z_i^2) z_i^2 + (z_2^2+1) z_2^2 - t^2 = 0$$
(16)

quotiented by a \mathbb{Z}_2 acting as $(z_1, z_2, z_3, z_4) \rightarrow (-z_1, z_2, -z_3, -z_4).$

We are now ready to lift to F-theory, we just build a CY fourfold with base $\mathcal{B} = X/\mathbb{Z}_2$. It will be a complete intersection on

	z_1	z_2	z_3	z_4	z_5	Λ	x	y	z	
\mathbb{C}_1^*	1	1	1	1	1	0	0	0	-1	· (17
\mathbb{C}_2^*	1	0	1	1	0	2	0	0	-1	(17
\mathbb{C}_3^*	0	0	0	0	0	0	2	3	1	

We are now ready to lift to F-theory, we just build a CY fourfold with base $\mathcal{B} = X/\mathbb{Z}_2$. It will be a complete intersection on

	z_1	z_2	z_3	z_4	z_5	Λ	x	y	z	
\mathbb{C}_1^*	1	1	1	1	1	0	0	0	-1	(17
\mathbb{C}_2^*	1	0	1	1	0	2	0	0	-1	(17)
\mathbb{C}_3^*	0	0	0	0	0	0	2	3	1	

We have also checked tadpole cancellation, and the absence of Freed-Witten anomalies.