Global models with D3 and D7 branes at singularities and moduli stabilisation

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Introduction

Two longstanding problems of string compactifications:

1) Moduli stabilisation;
2) Derivation of GUT- or MSSM-like constructions.

Md stab studied in many corners of Landscape. We chose to work in type IIB:

- Fluxes stabilise complex structure moduli and axiodilaton.
- Fluxes have mild backreaction to geometry (GKP).
- Viable mechanisms to fix Kähler moduli: KKLT, LVS, D-terms.

[Balasubramanian, Berglund, Blumenhagen, Burgess, Conlon, Dasgupta, Denef, Douglas, Dudas, Giddings, Grimm, Haack, Hebecker, Kachru, Kallosh, Klemm, Linde, Louis, Lüst, Jockers, Maharana, Mayr, Plauschinn, Polchinski, Quevedo, Raby, Sethi, Stieberger, Taylor, Theisen, Trivedi, Weigand, Westphal, Zagermann....]

In the last years increasing of model building in type IIB with D7-branes

- In type IIB model building, one can use complex geometry techniques.
- F-theory: 7-brane/geometric moduli and 3-form/gauge fluxes unified.
- Local models with magnetized branes and branes at singularities, and recently global models (both perturb type IIB and F-theory).

[Aldazabal, Beasley, Berglund, Blumenhagen, Braun, Collinucci, Conlon, Donagi, Dudas, Grimm, Heckman, Ibanez, Kreuzer, Krippendorf, Marchesano, Marsano, Mayrhofer, Palti, Quevedo, Saulina, Schafer-Nameki, Shiu, Uranga, Vafa, Verlinde, Watari, Weigand, Wijnholt.....]

Usually, 1) and 2) studied indipendently. $\rightarrow$ It's time to combine them!

Introduction

Three crucial issues in combining (global) model build with md stabilisation:

- $\ast$ There is tension between Kähler md stab by NP effects and chirality. [Blumenhagen,Moster,Plauschinn]

  $\Rightarrow$ Constraint on vis-sect flux: no chirality at inters with NP cycle.
  Best place to put NP effect is del Pezzo surface. [Cicoli,Kreuzer,Mayrhofer]
  (Also solution for $h^{1,1}_{-}(X) > 0$ [Grimm,Kerstan,Palti,Weigand])

- $\ast$ Freed-Witten anomaly generically prevents more than one NP effect. [Blumenhagen,Braun,Grimm,Weigand; Collinucci,Kreuzer,Mayrhofer,Walliser]
  $\mathcal{F} = F - B = 0$ on NP-cycle $\rightarrow$ B fixed. But generically $\mathcal{F} \neq 0$ elsewhere.

  $\Rightarrow$ Kähler moduli stabilisation by only one NP effect.
  (In specific examples one can have more cycles contributing.)

- $\ast$ Flux-generated D-terms can induce shrinking of 4-cycles (supporting visible sector), leading to the boundary of Kähler cone. [Blumenhagen,Braun,Grimm,Weigand; Collinucci,Kreuzer,Mayrhofer,Walliser; Cicoli,Kreuzer,Mayrhofer]

  $\Rightarrow$ If we don't want D3 at sing, avoid visible sector on dP.

(Moreover, control over EFT and stabilise Kähler moduli inside Kähler cone.)

Strategy

Type IIB CY orientifolds, with D3/D7-branes and O3/O7-planes.

- ▷ Phenomenological requirements translate to geometric properties of the compact manifold.
  - ∗ Set of geometric constraints consistent with phenom viable model.
  - ∗ Search for glob defined compact manifold satisfying such constr's.
- ▷ We take CY 3-folds from reduced lists of hypersurfaces in toric varieties $\rightarrow$ allow to be very explicit on CY topology and systematic in the search.
- ▷ After choosing a proper O7-involution, take a phenomenologically interesting brane setup with intersecting and (fluxed) D7-branes or with D3-branes at dP_n singularities.
- ▷ Check consistency conditions (like D7/D5/D3-tadpole cancellation, FW anomaly cancellation,...).
- ▷ Assuming c.s. fixed by 3-form fluxes (W_0, g_s parameters), study Kähler md stab in a way that addresses previous issues [Cicoli, Mayrhofer, R.V.].
- ▷ Fixed values of moduli set M_s, M_{susy},... and the vacuum energy. In two explicit examples, we found a dS vacuum (D-terms [Cicoli, Krippendorf, Mayrhofer, Quevedo, R.V.] and F-terms [Louis, Rummel,R.V., Westphal] uplift).

Outline

1. D-branes at singularities, local and global models
2. Explicit example with global embedding of local models and moduli stabilisation
3. Transitions among quivers
4. Conclusions and outlook.

D-branes at singularities

and

local/global models

D-branes at singularities and quiver theories

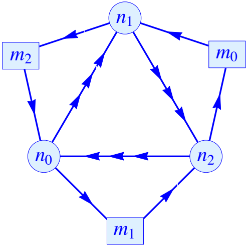
Consider models where the CY X develops point-like singularities.
One can then obtain chiral matter by putting D3 branes on top of sing.

- D3-branes split into fractional branes. [Douglas,Moore; Douglas,Diaconescu,Gomis]
  Associated quiver theory: for each fractional brane we draw a node, for each massless open string from brane i to brane j we draw an arrow.
- So far great attention on phenomenologically interesting local models, with MSSM-like gauge group and spectrum. [Aldazabal,Ibanez,Quevedo,Uranga; Berenstein,Jejjala,Leigh; Verlinde,Wijnholt; Dolan,Krippendorf,Quevedo...]
- We want globally defined compact models. Need to embed local quiver model into an orientifold of a compact singular CY_3.
  (Non-trivial: compact manifold very specific, in order to realise the embedding and to have moduli stabilisation; on top of it, charge cancellation.)
- See [Diaconescu, Florea, Kachru, Svrcek; Buican, Malyshev, Morrison, H.Verlinde, Wijnholt] for first global embeddings of dP_n singularities, and [Balasubramanian, Berglund, Braun, García-Etxebarria] for sistematic construction of toric singularities in compact CYs and embedding of quivers (with flavour D7-branes).

dP_0 singularity and associated quiver theory

We consider pt-like sing obtained by shrinking one $dP_0 = \mathbb{CP}^2$ in the CY_3.

- It is the orbifold sing $\mathbb{C}^3/\mathbb{Z}_3$: There are 3 fractional branes, in one-to-one corresp with irreducible rep of orbif group.
- Associated quiver theory $SU(n_0) \times SU(n_1) \times SU(n_2)$, with flav branes:



Anomaly cancellation constrains multiplicities of flav branes:

$$m_0 = m + 3(n_1 - n_0) \qquad m_1 = m \qquad m_2 = m + 3(n_1 - n_2) \qquad (m \in \mathbb{Z})$$

> To globally embed the local model, need to express fractional and flavour branes in terms of the geometry of the global model.

D-brane charges

D-brane charges encoded into the Mukai charge vector:

$$\Gamma_{\mathcal{E}} = [D] \cdot \text{ch}(\mathcal{E}) \cdot \sqrt{\frac{\text{Td}(TD)}{\text{Td}(ND)}} \qquad \hookrightarrow \begin{cases} \text{2-form} \leftrightarrow \text{D7-charge} \\ \text{4-form} \leftrightarrow \text{D5-charge} \\ \text{6-form} \leftrightarrow \text{D3-charge} \end{cases}$$

- Fractional branes described by well-chosen collection of sheaves, supported on shrinking cycle (7-branes). For $\mathbb{C}^3/\mathbb{Z}_3$ fractional branes:

$$\text{ch}(\mathcal{E}_0) = -1 + H - \tfrac{1}{2} H \wedge H\,, \quad \text{ch}(\mathcal{E}_1) = 2 - H - \tfrac{1}{2} H \wedge H\,, \quad \text{ch}(\mathcal{E}_2) = -1$$

and $D = \mathcal{D}_{dP_0}$ (H is hyperplane class of $dP_0 = \mathbb{P}^2$).

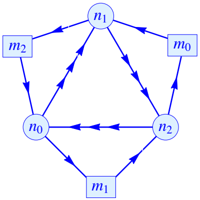
- Flavour branes are D7-branes wrapping holomorphic 4-cycles $\mathcal{D}_{\rm flav}$ that pass through the sing (i.e. $\mathcal{D}_{\rm flav} \cdot \mathcal{D}_{dP_0} \neq 0$):

$$\Gamma_{D7_{\rm flav}} = \mathcal{D}_{\rm flav} + \mathcal{D}_{\rm flav} \wedge \mathcal{F}_{\rm flav} + \mathcal{D}_{\rm flav} \wedge \left[\tfrac{1}{2}\mathcal{F}^2_{\rm flav} + \tfrac{1}{24} c_2(\mathcal{D}_{\rm flav})\right]$$

Local models only say what are the local charges of $D7_{\rm flav}$, i.e. restriction of $\Gamma_{D7_{\rm flav}}$ on $\mathcal{D}_{dP_0}$.

Restrictions on m_i

From number of chiral intersections between flav and fract branes $\Rightarrow$ local flav brane charges



$$\Gamma^{\rm loc}_{D7_0} = (m + 3(n_1 - n_0))H\left[1 + \tfrac{1}{2}H\right]$$

$$\Gamma^{\rm loc}_{D7_1} = -2mH\,[1 + H]$$

$$\Gamma^{\rm loc}_{D7_2} = (m + 3(n_1 - n_2))H\left[1 + \tfrac{3}{2}H\right]$$

with $\Gamma^{\rm loc}_{D7} \equiv \Gamma_{D7_{\rm flav}}|_{dP_0} = a\,H + b\,H^2$

- ⋇ In particular, $\mathcal{D}_{\rm flav}|_{dP_0} = a\,H$ is 2-form P.D. to the intersection $\mathcal{D}_{\rm flav} \cap \mathcal{D}_{dP_0}$.
- ⋇ $\mathcal{D}_{\rm flav}$ is connected and $\mathcal{D}_{\rm flav} \cap \mathcal{D}_{dP_0}$ is effective curve $\Rightarrow a > 0$.

The locally induced D7-charge of a flav brane must be postive multiple of H.

$$\Rightarrow \qquad 0 \leq -m \leq 3(n_1 - \max\{n_0, n_2\})$$

$\hookrightarrow$ *Not all* local models are realised globally. E.g., if $n_0 = n_1 = n_2$ then $m_i = 0$.

Explicit global embedding

of a local model

with moduli stabilisation

Explicit global quiver model: geometry

We take CY_3 X, that is a hypersurface in a 4d toric ambient variety:

z_1	z_2	z_3	z_4	z_5	z_6	z_7	z_8	D_{eq_X}
1	1	1	0	3	3	0	0	9
0	0	0	1	0	1	0	0	2
0	0	0	0	1	1	0	1	3
0	0	0	0	1	0	1	0	2

$$\mathrm{SR} = \{z_4\, z_6,\; z_4\, z_7,\; z_5\, z_7,\; z_5\, z_8,\; z_6\, z_8,\; z_1\, z_2\, z_3\}$$

CY data obtained from PALP output [Kreuzer,Skarke].

- Hodge numbers: $h^{1,1}(X) = 4$, $h^{1,2}(X) = 112$.
- Basis of $H_4(X)$:

$$\mathcal{D}_b = D_4 + D_5 = D_6 + D_7, \qquad \mathcal{D}_{q_1} = D_4, \qquad \mathcal{D}_{q_2} = D_7, \qquad \mathcal{D}_s = D_8$$

- Intersection form $I_3 = 27\mathcal{D}_b^3 + 9\mathcal{D}_{q_1}^3 + 9\mathcal{D}_{q_2}^3 + 9\mathcal{D}_s^3$.
- There are three dP_0 at $z_4 = 0$, $z_7 = 0$ and $z_8 = 0$.
- We have $D_1|_{\mathcal{D}_{dP_0}} = H$ (where $\mathcal{D}_{dP_0} = \mathcal{D}_{q_1}, \mathcal{D}_{q_2}, \mathcal{D}_a$).

Orientifold projection and Kähler moduli

We take an orientifold involution that exchanges two (shrinking) dP_0s:

$$\sigma \; : \qquad z_4 \leftrightarrow z_7 \qquad \text{and} \qquad z_5 \leftrightarrow z_6 \qquad (h^{1,1}_-(X){=}1 \text{ and } h^{1,1}_+(X){=}3)$$

- The two dP_0s $\mathcal{D}_{q_1} = D_4$ and $\mathcal{D}_{q_2} = D_7$ are exchanged.
- There are no O3-planes and two O7-planes: $O7_1$ at $z_4 z_5 - z_6 z_7 = 0$ and $O7_2$ at $z_8 = 0 \to [O7_1] = \mathcal{D}_b$ and $[O7_2] = \mathcal{D}_s$.
- O7-planes do not intersect the (shrinking) dP_0s and do not intersect each others.
- Symmetric Kähler form: $J = t_b \mathcal{D}_b + t_s \mathcal{D}_s + t_{\rm shr}(\mathcal{D}_{q_1} + \mathcal{D}_{q_2})$:

$$\text{vol}(\mathcal{D}_{q_1}) = \text{vol}(\mathcal{D}_{q_2}) = \tfrac{9}{2} t_{\rm shr}^2 \,, \qquad \text{vol}(\mathcal{D}_s) = \tfrac{9}{2} t_s^2 \,, \qquad \text{vol}(X) = 3(\tfrac{3}{2} t_b^3 + t_{\rm shr}^3 + \tfrac{1}{2} t_s^3)$$

- Kähler cone:

$$t_b + t_s > 0 \qquad -t_s > 0 \qquad t_b + t_{\rm shr} > 0 \qquad -t_{\rm shr} > 0$$

Singular CY at $t_{\rm shr} \to 0$.

Model without flavour branes

Visible sector from $N = 3$ D3-branes on top of each (of the two) sing.
$n_0 = n_1 = n_2 = 3$

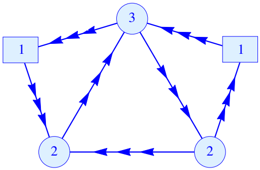
- dP_0 quiver theory (trinification model - $SU(3)_c \times SU(3)_L \times SU(3)_R$ with chiral spectrum $3\left[\left(3,\overline{3},1\right) + \left(1,3,\overline{3}\right) + \left(\overline{3},1,3\right)\right]$).

To cancel D7-charge of O7-plane:
put 4 D7 (plus images) on top of each O7-plane.

- Hidden group $SO(8) \times SO(8)$.
- FW flux $F_s = -\frac{\mathcal{D}_s}{2}$ cancelled by choosing $B = -\frac{\mathcal{D}_s}{2}$.
  - $\hookrightarrow$ $\mathcal{F}_s = F_s - B = 0 \rightarrow$ pure $SO(8)$ SYM on rigid $\mathcal{D}_s$ (gaugino condens).
- FW flux $F_b = -\frac{\mathcal{D}_b}{2}$ also cancelled if $B = -\frac{\mathcal{D}_b}{2} - \frac{\mathcal{D}_s}{2}$.
  - $\hookrightarrow$ There areadjoint scalars; if they are lift by appropriate flux [Biachi, Collinucci, Martucci], we can have non-pert effects also from $\mathcal{D}_b$ (KKLT).

Model *with* flavour branes

We want to realise the following quiver theory at the sing:



Left-Right symmetric model

$$SU(3)_c \times SU(2)_L \times SU(2)_R$$

with $n_0 = n_2 = 2$, $n_1 = 3$ and $m = 0$
($m_0 = m_2 = 3$ and $m_1 = 0$)

Local $D7_{\rm flav}$ charges: $\Gamma^{\rm loc}_{D7_0} = 3H(1 + \frac{1}{2}H)$ and $\Gamma^{\rm loc}_{D7_2} = 3H(1 + \frac{3}{2}H)$

- D7-charge: for both flav branes $\mathcal{D}_{\rm flav}|_{\mathcal{D}_{q_1}} = 3H$. Hence,

$$\mathcal{D}_{\rm flav} = 3D_1 + \alpha^b \mathcal{D}_b + \alpha^s \mathcal{D}_s + \alpha^{q_2} \mathcal{D}_{q_2}$$

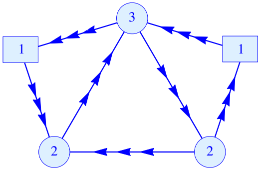
Require they do not intersect $\mathcal{D}_s$ and $\mathcal{D}_{q_2}$:

$$\mathcal{D}^{(0)}_{\rm flav} = 3D_1 + \mathcal{D}_s + \mathcal{D}_{q_2} + \alpha^b_0 \mathcal{D}_b = (1 + \alpha^b_0)\mathcal{D}_b - \mathcal{D}_{q_1}$$

$$\mathcal{D}^{(2)}_{\rm flav} = 3D_1 + \mathcal{D}_s + \mathcal{D}_{q_2} + \alpha^b_2 \mathcal{D}_b = (1 + \alpha^b_2)\mathcal{D}_b - \mathcal{D}_{q_1}$$

Model *with* flavour branes

We want to realise the following quiver theory at the sing:



Left-Right symmetric model

$$SU(3)_c \times SU(2)_L \times SU(2)_R$$

with $n_0 = n_2 = 2$, $n_1 = 3$ and $m = 0$
($m_0 = m_2 = 3$ and $m_1 = 0$)

Local $D7_{\rm flav}$ charges: $\Gamma^{\rm loc}_{D7_0} = 3H(1 + \frac{1}{2}H)$ and $\Gamma^{\rm loc}_{D7_2} = 3H(1 + \frac{3}{2}H)$

- D5-charge: fluxes are different on two flav branes: $\mathcal{F}_0|_{\mathcal{D}_{q_1}} = \frac{1}{2}H$ and $\mathcal{F}_2|_{\mathcal{D}_{q_1}} = \frac{3}{2}H$. Moreover, pull-back of $\mathcal{D}_s$ and $\mathcal{D}_{q_2}$ on divisor $3D_1 + \mathcal{D}_s + \mathcal{D}_{q_2} + \alpha^b\mathcal{D}_b$ are trivial. Hence,

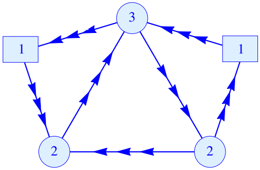
$$\mathcal{F}^{(0)}_{\rm flav} = \frac{1}{2}D_1 + \beta^b_0\mathcal{D}_b \qquad \mathcal{F}^{(2)}_{\rm flav} = \frac{3}{2}D_1 + \beta^b_2\mathcal{D}_b$$

- D3-charge:

$$\mathcal{D}_{\rm flav} \cdot \left[\frac{1}{2}\mathcal{F}^2_{\rm flav} + \frac{c_2(\mathcal{D}_{\rm flav})}{24}\right]$$

Model *with* flavour branes

We want to realise the following quiver theory at the sing:



Left-Right symmetric model

$$SU(3)_c \times SU(2)_L \times SU(2)_R$$

with $n_0 = n_2 = 2$, $n_1 = 3$ and $m = 0$
($m_0 = m_2 = 3$ and $m_1 = 0$)

The charges from the quiver system (including fractional branes) are

$$\Gamma_{\text{fractionalD3}} = 2\Gamma_{\mathcal{E}_0} + 3\Gamma_{\mathcal{E}_1} + 2\Gamma_{\mathcal{E}_2} = 2\mathcal{D}_{q_1} + 2\mathcal{D}_{q_1} \wedge D_1 - \frac{3}{2} dVol_X^0$$

$$\Gamma_{D7_0^{\text{flav}}} = (\mathcal{D}_b - \mathcal{D}_{q_1}) + (\mathcal{D}_b - \mathcal{D}_{q_1}) \wedge \left(\frac{1}{2} D_1 + \beta_0^b \mathcal{D}_b\right) + \left\{5 + \frac{3}{2}\beta_0^b(1 + 9\beta_0^b)\right\} dVol_X^0$$

$$\Gamma_{D7_2^{\text{flav}}} = (\mathcal{D}_b - \mathcal{D}_{q_1}) + (\mathcal{D}_b - \mathcal{D}_{q_1}) \wedge \left(\frac{3}{2} D_1 + \beta_2^b \mathcal{D}_b\right) + \left\{7 + \frac{27}{2}\beta_2^b(1 + \beta_2^b)\right\} dVol_X^0$$

where $\int_X dVol_X^0 = 1$ and we chose $\alpha_0^b = \alpha_2^b = 0$.

Summing 3 vect's, with $\beta_0^b = \beta_0^b = 0$: $\Gamma_{\text{quiver}}^{z_4=0} = 2\mathcal{D}_b + 2\mathcal{D}_b \wedge D_1 + \left(\frac{27}{2} - 3\right) dVol_X^0$

Other D7-branes

Two O7-planes, one at $\mathcal{D}_s$ and one at $\mathcal{D}_b$. We need to saturate their tadpole:

- Four D7-branes (plus images) wrapping $\mathcal{D}_s$. B-field cancel FW-flux. $SO(8)$ gauge group.
- To cancel tadpole of $[O7_1] = \mathcal{D}_b$, we need two more D7-branes (plus images) wrapping $\mathcal{D}_b$. $SO(4)$ gauge group

  (unless there is flux $\mathcal{F}_b = (\frac{1}{2} + f)D_1$: $U(2)$ gauge group).
- D7- and D5-charges cancel globally. Net D3-charge:

$$\begin{aligned} Q_{D3}^{\rm tot} &= Q_{D3}^{\text{quiver; } z_4=0} + Q_{D3}^{\text{quiver; } z_7=0} + Q_{D3}^{U(2)} + Q_{D3}^{SO(8)} \\ &= -63 - 3\left[\beta_0(1+9\beta_0) + 9\beta_2(1+\beta_2) + 2f(1+f)\right] \end{aligned}$$

Fluxes on the flavour branes and on the $U(2)$-stack can generate

- ▷ Chiral modes at their intersections (and bulk of $U(2)$).
- ▷ Non-zero FI-terms.

Moduli Stabilisation

'Step by step' stabilisation:

- Complex structure md and D7-deformations stabilised by fluxes.
- D-terms on the visible sector stabilise $t_{\rm shr} \to 0$:

$$V_D = \frac{1}{\mathrm{Re}(f_1)} \left(\sum_i q_{1i} K_i C_i - \xi_1 \right)^2 + \frac{1}{\mathrm{Re}(f_2)} \left(\sum_i q_{2i} K_i C_i - \xi_2 \right)^2$$

For vanishing vev of matter fields C_i, min at $\xi_1 = \xi_2 = 0$, where

$$\xi_1 = -4 q_1 \frac{\tau_+}{\mathcal{V}} \qquad (\tau_+ \propto t_{\rm shr}^2) \qquad \xi_2 = -4 q_2 \frac{b}{\mathcal{V}}$$

- Gaugino condensation on rigid $\mathcal{D}_s$ (a dP_0), $W_0 \sim \mathcal{O}(1)$ and α' corr:

  $\hookrightarrow$ F-term potential stabilises τ_s small and $\mathcal{V}$ LARGE.

We can realize a dS vacuum in the LVS case:

- Switch on gauge flux on non-rigid $SO(4)$ stack: it generates bulk chiral matter and FI-term. $\Rightarrow$ D-term uplift: $V_{\rm uplift} \sim \frac{W_0^2}{\mathcal{V}^{8/3}}$. We obtain a 'tiny' dS.

Transitions

among

quivers

Transitions in the example ?

Total charge of quiver system ($SU(3) \times SU(2)^2$ plus two flav branes)

$$\Gamma^{z_4=0}_{\text{quiver}} = 2\mathcal{D}_b + 2\mathcal{D}_b \wedge D_1 + \left(\tfrac{27}{2} - 3\right) dVol^0_X$$

This may be realised by another configuration:

- Three D3-branes at the singularity, realising an $SU(3)^3$
- Two D7-branes wrapping the divisor $\mathcal{D}_b$ (i.e. *not* passing through the singularity) and with fluxes $\mathcal{F} = \frac{1}{2}D_1, \frac{3}{2}D_1$:

$$\begin{aligned} \Gamma^{SU(3)^3}_{\text{quiver}} &= -3\, dVol^0_X \\ \Gamma_{D7_0} &= \mathcal{D}_b + \mathcal{D}_b \wedge \tfrac{1}{2}D_1 + \tfrac{21}{4} dVol^0_X \\ \Gamma_{D7_2} &= \mathcal{D}_b + \mathcal{D}_b \wedge \tfrac{3}{2}D_1 + \tfrac{33}{4} dVol^0_X \end{aligned}$$

This suggests a possible transitions between the two susy configurations with the same charges.

From $SU(3)^3$ to $SU(3)^2 \times SU(2)$

Let us study first an analogous transition

Initial configuration:

- $SU(3)^3$ quiver (without flav br) with total charge $\Gamma^{SU(3)^3}_{\text{quiver}} = -3\, dVol^0_X$.
- Bulk brane with charge $\Gamma_{D7_0} = \mathcal{D}_b + \mathcal{D}_b \wedge \frac{1}{2} D_1 + \frac{21}{4} dVol^0_X$.

Final configuration:

- $SU(3)^2 \times SU(2)$ quiver and one fractional brane with total charge

$$\Gamma^{SU(3)^2 \times SU(2)}_{\text{quiver}} = \mathcal{D}_b + \mathcal{D}_b \wedge \frac{1}{2} D_1 + \frac{9}{4} dVol^0_X \ .$$

* Charges are conserved.
* Before, a D7-brane that does not pass through the singularity and $SU(3)^3$ quiver at the singularity.
* Afterwards, a D7(flavour)-brane passes through the sing and quiver gauge group changes!

Toy model

Transition seems to occur when bulk D7 touches sing.

Consider the following space

x_0	x_1	x_2	y
1	1	1	3

- $\mathbb{C}^3/\mathbb{Z}_3$ singulartity at $x_0 = x_1 = x_2 = 0$. Put 3 D3-branes there.
- Take D7-brane wrapping $P_3(x_i) + \alpha\, y = 0$.
- Let $\alpha \to 0$: D7 touches sing and transition on quiver should occur.

Let us see what happens in the resolved picture:

x_0	x_1	x_2	y	z
1	1	1	3	0
0	0	0	1	1

- $z = 0$ is the blown-up dP_0.
- Bulk D7 is $z \cdot P_3(x_i) + \alpha\, y = 0$.
- At $\alpha \to 0$ D7 splits into flavour brane and a brane wrapping dP_0.

Transitions in the example

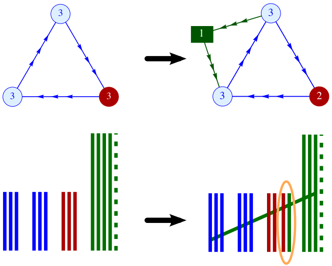
For an interpretation, go to large volume (blow-up). Effective description:

Take D7 on $\mathcal{D}_b$ and split it into a brane on $\mathcal{D}_b - \mathcal{D}_{q_1}$ and a brane on $\mathcal{D}_{q_1}$ with

$$\Gamma_{D7_0^{\rm flav}} = (\mathcal{D}_b - \mathcal{D}_{q_1}) + (\mathcal{D}_b - \mathcal{D}_{q_1}) \wedge \tfrac{1}{2} D_1 + 5\, dVol_X^0$$

$$\Gamma_{\mathcal{D}_{q_1}} = \mathcal{D}_{dP_0} + \mathcal{D}_{dP_0} \wedge \tfrac{1}{2} D_1 + \tfrac{1}{4}\, dVol_X^0 = -\Gamma_{\mathcal{E}_0}$$

Splitting generates the flavour brane $D7_0^{\rm flav}$ and an ‘anti-fractional’ brane that annihilates with one fractional brane at the 0-node of the quiver.

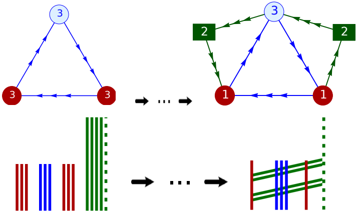


Repeating this, we can go to the L-R symmetric model and further to SM.

Web of D-brane models at singularities

Claim: connect all the quiver models that can be embedded into CY three-fold

Bound given by D-brane charge conserv. E.g.



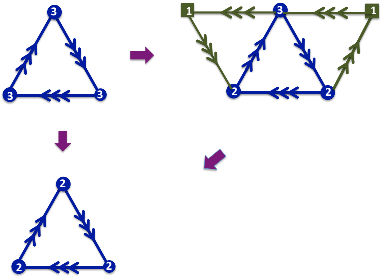
This phenomenon (described in one example) is valid for any global embed of dP_0 quiver models, and should work analogously also for other dP_n.

From $SU(3)^3$ to $SU(2)^3$

Transition from $SU(3)^3$ to $SU(2)^3$:

Either take one D3-brane away from the singularity, or

- ↪ Take two bulk D7s and undergo transitions to $SU(3) \times SU(2)^2$.
- ↪ Recombine two flav branes and fractional brane at node $n_1 = 3$. This give a bulk D7 with non-abelian flux.
- ↪ D7 expels one D3-brane and split into the initial bulk D7s.



Conclusions

- We studied how to embedd dP_0 quiver models with and without flavour branes, into a compact manifold.
- We found restrictions on local models that can be embedded in this way.
- We have described explicit global embedding of a dP_0 quiver model.
- Geometric data described by toric geometry. This allowed us to make specific choice of brane setup and fluxes.
- We were able to combine various mechanisms to stabilise Kähler moduli, without violating global consistency conditions and overcoming problems found so far. We found dS vacua.
- We considered the possibility of transitions between quiver models.

Outlook

- There is a long list of CY_3 in PALP output: try to automatise the search for consistent and phenomenological viable models.
- Study phenomenology of L-R symmetric (global) model.
- Study complex structure moduli stabilisation: see if one can stabilise all of them and what 3-form fluxes one can switch on.
- Uplift to F-theory (more control over complex structure and open string moduli; flux quantisation).
- Understand the dynamics of transitions among quivers.

Moduli stabilisation

Moduli Stabilisation in Type IIB

Take Type IIB compactified on CY_3 X with orientifold invol $(-1)^{F_L}\Omega_p\sigma$.

- Moduli: $h^{1,2}_-$ c.s., $h^{1,1}_+$ $\mathbb{C}$-fied Käh, $h^{1,1}_-$ (B, C_2) and $S = e^{-\phi} + iC_0$.
- The tree-level 4D Kähler potential takes the form [Grimm,Louis]:

$$K_{\text{tree}} = -2\ln\mathcal{V} - \ln\left(S+\bar{S}\right) - \ln\left(-i\int_X \Omega\wedge\bar{\Omega}\right)$$

  depends on c.s. md via Ω, while on Kähler md via the CY vol $\mathcal{V} = \frac{1}{6}\int_X J\wedge J\wedge J = \frac{1}{6}\, k_{ijk}t^it^jt^k$, where $J = t^i\hat{D}_i$.
- A tree-level superpotential is generated by turning on bkgr fluxes $G_3 = F_3 + iSH_3$ ($F_3 = dC_2$ and $H_3 = dB_2$) [Gukov,Vafa,Witten]:

$$W_{\text{tree}} = \int_X G_3\wedge\Omega$$

- F-term potential:

$$V_F^{\text{tree}} = e^K\left(|D_IW|^2 - 3|W|^2\right) = e^K|D_iW|^2 \qquad i \text{ over } S \text{ and c.s. md}$$

  $\hookrightarrow$ Tree-level potential has no-scale structure; at min, Kähler md are flat directions, while c.s. md and S are fixed (at $D_iW = 0$).

Kähler moduli stabilisation

Sources for Kähler md stab $\rightarrow$ other terms in the potential

$$V = V_F^{\text{tree}} + V_D + \delta V_F^{\text{pert}} + \delta V_F^{\text{np}}$$

V_D : D-term potential (generated by fluxes on D7's) [Jockers,Louis].

δV_F^{pert} : perturbative α' [Becker,Becker,Haack,Louis] and g_s [Becker,Haack, Kors, Pajer] corrections to the Kähler potential K.

δV_F^{np} : non-perturbative corrections to the superpotential W (E3-instantons or gaugino condensation on a D7-stack) [Witten; Kachru,Kallosh,Linde,Trivedi].

- At leading order in $1/\mathcal{V}$, min at $V_F^{\text{tree}} = 0$ and $V_D = 0$.
  $\hookrightarrow$ dilaton and c.s. md fixed at their flux-stabilised values.
- At subleading order $\rightarrow$ minimize δV_F
  (g_s and $W_0 = \langle W_{\text{tree}} \rangle$ flux-dependent constants. $K = -2 \ln \mathcal{V}$, with c.s. and dilaton parts of K entering as an overall factor.)