F-theoretic MSSMs at Weak Coupling

Damián K. Mayorga Peña

Based on **arXiv: 1707.xxxx**, in collaboration with Roberto Valandro

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Plan

- Introduction and motivation
- The Sen limit of an MSSM-like model
- A two U(1) model
- (not so) Exotic Matter in the type IIB limit
- Conclusions and Prospects

Introduction and motivation

- F-theory exhibits a promising phenomenology, mostly explored in the context of SU(5) GUTs.

  Antoniadis, Beasley, Braun, Colinucci,Dolan, Dudas, Grimm, Hayashi, Heckman, Keitel, Leontaris, Marchesano, Marsano, Mayrhofer, Palti, Schäfer Nameki, Vafa,Valandro, Watari, Weigand,…

- ...there are (in principle) other alternatives. Here we consider some of such alternatives motivated from the study of toric hypersurface fibers...the bare MSSM and a U(1) extended MSSM,

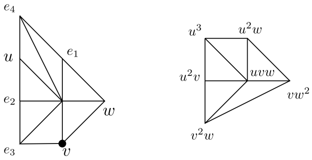
  Lin, Weigand'14'16; Grassi, Halverson, Shaneson, Taylor'14; Cvetič, Klevers, DM, Oehlmann, Piragua, Reuter'15; see Ling's, Mirjam's and Wati's talks

- Do these constructions have a description as intersecting D7 orientifold models in perturbative type IIB string theory?

  Blumenhagen, Grimm, Jurke, Weigand'09; Krause, Mayrhofer, Weigand'12

An MSSM-like model

Cvetič, Klevers, DM, Oehlmann, Piragua, Reuter'15



The fiber is cut by the cubic

$$p_{F_{11}} = s_1 e_1^2 e_2^2 e_3 e_4^4 u^3 + s_2 e_1 e_2^2 e_3^2 e_4^2 u^2 v + s_3 e_2^2 e_3^2 u v^2 + s_5 e_1^2 e_2 e_4^3 u^2 w + s_6 e_1 e_2 e_3 e_4 u v w + s_9 e_1 v w^2$$

as $\{p_{F_{11}} = 0\}$.

It can be mapped to the WSF by means of Nigell's algorithm, with

$$f = \frac{1}{48}[-s_6^2 + \ldots]\,, \quad g = \frac{1}{864}[s_6^6 + \ldots]\,, \quad \Delta = \frac{1}{16} s_3^2 s_9^3 [\ldots]$$

Hence we have an SU(3) at $\{s_9 = 0\}$ and an SU(2) at $\{s_3 = 0\}$, as well as two rational sections with fiber coords:

$$S_0 \; : \quad [x : y : z] = [1 : 1 : 0]\,, \quad S_1 \; : \quad [x : y : z] = \left[\frac{s_6^2 - 4 s_2 s_9}{12} : \frac{s_3 s_5 s_9}{2} : 1 \right].$$

These sections provide the hypercharge U(1) generator.

Introduction and motivation

at codimension two:

Representation	Locus
$(\mathbf{3},\mathbf{2})_{1/6}$	$V(I_{(1)}) := \{s_3 = s_9 = 0\}$
$(\mathbf{1},\mathbf{2})_{-1/2}$	$V(I_{(2)}) := \{s_3 = s_2 s_5^2 + s_1(s_1 s_9 - s_5 s_6) = 0\}$
$(\bar{\mathbf{3}},\mathbf{1})_{-2/3}$	$V(I_{(3)}) := \{s_5 = s_9 = 0\}$
$(\bar{\mathbf{3}},\mathbf{1})_{1/3}$	$V(I_{(4)}) := \{s_9 = s_3 s_5^2 + s_6(s_1 s_6 - s_2 s_5) = 0\}$
$(\mathbf{1},\mathbf{1})_{1}$	$V(I_{(5)}) := \{s_1 = s_5 = 0\}$

the chiralities are obtained after fixing the (vertical) G_4-flux, which by recent methods can be obtained in a base independent fashion.

Lin, Weigand'16

$$H^{(4,4)}(X) \cong \frac{\mathbb{Q}[D_A]^4 \wedge [P_{F_{11}}]}{\text{SRI} + \text{LIN}} \subset H^{(5,5)}(X_5)\,.$$

For this case, the flux expression reads

$$G_4 = \mathcal{F} \wedge \sigma(S_1) + \Lambda\left(6[K_B^{-1}]^2 + [K_B^{-1}]S_0 + S_0^2 - 5[K_B^{-1}]\mathcal{S}_7 + \mathcal{S}_7^2 - 2[K_B^{-1}]\mathcal{S}_9 + \mathcal{S}_7\mathcal{S}_9\right)$$

The Sen limit of an MSSM

Sen'96; see Iñaki's talk

Make the coord. change $s = x - b_2 z^2/3$, with $b_2 = \frac{s_6^2}{4} - s_2 s_9$, such that the section S_1 touches the fiber at $s = 0$. The WSF reads

$$y^2 = s^3 + b_2 s^2 z^2 + 2 b_4 s z^4 + b_6 z^6 \,,$$

with

$$b_4 = \frac{s_3 s_9}{2}\left(-\frac{s_5 s_6}{2} + s_1 s_9\right) \,, \quad b_6 = \frac{s_3^2 s_5^2 s_9^2}{4} \,.$$

setting the scalings $s_1 \to \epsilon s_1$, $s_5 \to \epsilon s_5$, one gets $b_2 \to b_2$, $b_4 \to \epsilon b_4$, $b_6 \to \epsilon^2 b_6$.

- Gauge symmetry $SU(3) \times SU(2) \times U(1)$ for any ϵ.
- For $\epsilon = 0$ the fiber degenerates globally. Better study a resolved case

$$y^2 = s^3 \lambda + \tilde{b}_2 s^2 z^2 + 2 \tilde{b}_4 t s z^4 + \tilde{b}_6 t^2 z^6$$

  with $s \mapsto s\lambda$, $y \mapsto y\lambda$ and $\epsilon \mapsto t\lambda$.

The Sen limit of an MSSM

- At $\lambda = t = 0$

$$X_3 : \quad \xi^2 = \frac{s_6^2}{4} - s_2 s_9 \,;$$

with $\xi = y/sz$.

- In the limit $\lambda \to 0$, the equation

$$W_E \; : \quad y^2 = \tilde{b}_2 s^2 z^2 + 2\tilde{b}_4 tsz^4 + \tilde{b}_6 t^2 z^6$$

defines a $\mathbb{P}^1$ fibration degenerating whenever:

$$\Delta_E = \frac{s_3^2 s_9^3}{4} \left(s_1 s_5 s_6 - s_2 s_5^2 - s_1^2 s_9 \right) = 0 \,.$$

- Non Abelian symmetry is preserved in the Sen limit. Remaining piece responsible for the U(1).

The Sen limit of an MSSM

- **U(3)**:

$$X_3 \cap \{s_9 = 0\} \;:\quad (\xi - s_6/2)(\xi + s_6/2) = 0\,.$$

  We denote $W = \{s_9 = 0\} \cap \{\xi - s_6/2 = 0\}$ and its image $\tilde{W} = \{s_9 = 0\} \cap \{\xi + s_6/2 = 0\}$.

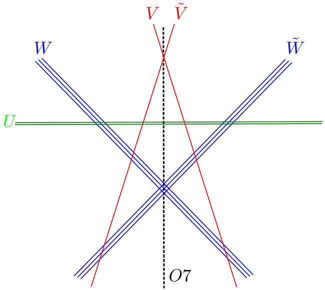
- **SU(2)**: $U = \{s_3 = 0\} \cup X_3$, does not split. $Sp(2) \equiv \mathrm{SU}(2)$.
- **U(1)**: $X_3 \cap \{s_1 s_5 s_6 - s_2 s_5^2 - s_1^2 s_9 = 0\}$ splits in such a way that

$$V = 4D_{O7} - (W + 2\tilde{W}) - U\,, \quad \tilde{V} = \sigma^* V\,,$$

  consistent with D7 tadpole cancellation

$$(V + \tilde{V}) + 2U + 3(W + \tilde{W}) = 8D_{O7}\,.$$

The Sen limit of an MSSM



The curve $(\overline{\mathbf{3}},\mathbf{1})_{1/3}$ splits at leading order in ϵ

$$\{s_9\,,\epsilon^2\, s_3 s_5^2 + \epsilon s_6(s_1 s_6 - s_2 s_5)\}\,,$$

the split curves are $(\overline{\mathbf{3}},\mathbf{1})_{(+1,-1)}$ at $\{s_9,\ (s_1 s_6 - s_2 s_5)\}$ and $(\overline{\mathbf{3}},\mathbf{1})_{(0,2)}$ at $\{s_9,\ s_6\}$.

Hypercharge

$$Q_Y = \frac{1}{6}(3Q_V + Q_W)\,,$$

Representation	
$(\mathbf{3},\mathbf{2})_{(0,1)}$	WU
$(\bar{\mathbf{3}},\mathbf{1})_{(-1,-1)}$	$\tilde{W}V$
$(\bar{\mathbf{3}},\mathbf{1})_{(1,-1)}$	$\tilde{W}\tilde{V}$
$(\bar{\mathbf{3}},\mathbf{1})_{(0,2)}$	$W\tilde{W}$
$(\mathbf{1},\mathbf{2})_{(-1,0)}$	UV
$(\mathbf{1},\mathbf{1})_{(2,0)}$	$V\tilde{V}$

The Sen limit of an MSSM

Matching Fluxes Gauge fluxes are constrained by cancellation of D5 tadpoles

$$0 = W_-(3F_+^W + F_+^V) + 3W_+(F_-^W - F_-^V) + 2U(F_-^U - F_-^V)$$

- **Pure even**:

$$(F_+^W, F_+^V) = (\frac{2\lambda}{3}D_{O7}, 0)\,, \quad (F_+^W, F_+^V) = (\frac{1}{6}F, -\frac{1}{2}F)\,..$$

- **Pure odd**: $F_-^W = F_-^V = F_-^U$ (can be reabsorbed in the B field).
- **Mixed**:

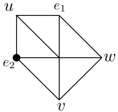
$$(F_+^W, F_-^W) = \alpha(-\frac{1}{3}W_+, \frac{1}{3}W_-)\,, \quad (F_+^W, F_-^U) = \beta(-\frac{1}{3}U, -\frac{1}{2}W_-)\,.$$

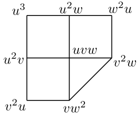
The counterpart of the Λ flux reads

$$F = -6\Lambda D_{O7} + 2\Lambda W_+ + 3\Lambda U\,, \quad \alpha - \lambda = 0\,, \quad \beta = 1\,.$$

A two U(1) model

Borchmann, Cvetič, Klevers, Mayrhofer, Palti, Piragua, Weigand



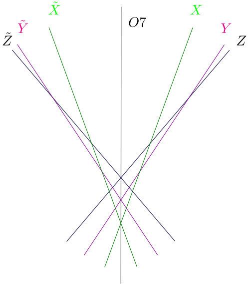


F-theory flux:

$$G_4 = \mathcal{F}_1 \wedge \sigma(S_1) + \mathcal{F}_2 \wedge \sigma(S_1) + \Lambda(S_0^2 + [K_B^{-1}](-[K_B^{-1}] + S_2) + \mathcal{S}_9(-\mathcal{S}_7 + \mathcal{S}_9))$$

Type IIB flux:

$$(F_X^+, F_Y^+, F_Z^+) = (F_1 - F_2, F_1, F_1 + F_2),$$
$$F_X^+ = \lambda D_{O7}, (F_X^+, F_Y^-) = \alpha(Y_+, -X_-).$$

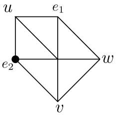


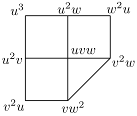
F-th. U(1) charges: $Q_1 = \frac{1}{2}(Q_X + Q_Y + Q_Z)$, $Q_2 = \frac{1}{2}(-Q_X + Q_Z)$.

~~$\mathbf{1}_{(2,0,0)}$~~	$\mathbf{1}_{(1,1,0)}$	$\mathbf{1}_{(1,-1,0)}$	$\mathbf{1}_{(1,0,1)}$	$\mathbf{1}_{(1,0,-1)}$	$\mathbf{1}_{(0,2,0)}$	$\mathbf{1}_{(0,1,1)}$	$\mathbf{1}_{(0,1,-1)}$	$\mathbf{1}_{(0,0,2)}$
$X\tilde{X}$	XY	$X\tilde{Y}^*$	XZ^{**}	$X\tilde{Z}$	$Y\tilde{Y}^{**}$	YZ	$Y\tilde{Z}^*$	$Z\tilde{Z}$

A two U(1) model

Borchmann, Cvetič, Klevers, Mayrhofer, Palti, Piragua, Weigand





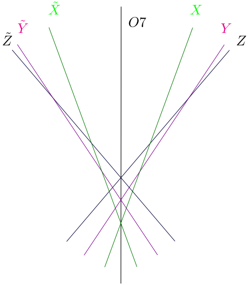
F-theory flux:

$$
\begin{aligned}
G_4 = & \mathcal{F}_1 \wedge \sigma(S_1) + \mathcal{F}_2 \wedge \sigma(S_1) \\
& + \Lambda(S_0^2 + [K_B^{-1}](-[K_B^{-1}] + S_2) + \mathcal{S}_9(-\mathcal{S}_7 + \mathcal{S}_9))
\end{aligned}
$$

flux matched by

$F_1 = 0, \quad F_2 = \Lambda(-2D_{O7} + X_+/2 + Y_+/2),$

$\lambda = -2\Lambda, \alpha = \Lambda/2.$



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$X\tilde{X}$	XY	$X\tilde{Y}^*$	XZ^{**}	$X\tilde{Z}$	$Y\tilde{Y}^{**}$	YZ	$Y\tilde{Z}^*$	$Z\tilde{Z}$

A two U(1) model

Adding an SU(3) × SU(2) top

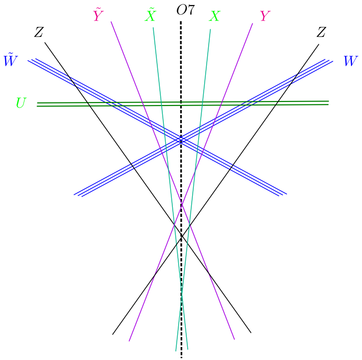
Lin, Weigand'14'16

- After adding the top the model continues to have a IIB limit.

$$X_3 : \quad \xi^2 = \frac{s_6^2}{4} - w s_5 s_7 \,;$$

instead of one, we get three conifold points.

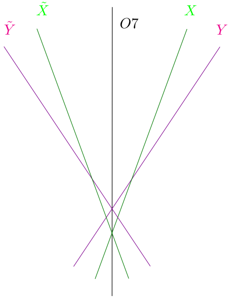
- In addition to the fluxes along the $\sigma(S_i)$, there are five extra flux directions in the F-theory model.
- ...in process of matching with type IIB fluxes.



$$Q_1 = \tfrac{1}{6}(Q_W + (Q_X + Q_Y + Q_Z)),$$
$$Q_2 = \tfrac{1}{3}(Q_W + (-Q_X + Q_Z))\,.$$

(not so) exotic matter in the IIB limit

A singlet with U(1) charge $q = 3$



$$q = 2Q_X + Q_Y$$

Representation	q
~~$\mathbf{1}_{(2,0)}$~~	
$\mathbf{1}_{(1,1)}$	3
$\mathbf{1}_{(1,-1)}$	1
$\mathbf{1}_{(0,2)}$	2

The absence of conifold points removes some matter representations, upon realignment of the U(1) charges we find more exotic configurations. How does this extend to non-Abelian exotic matter?

Cvetič, Klevers, Morrison, Piragua, Raghuram, Taylor

Conclusions

- We have worked out the Sen limit of some MSSM models constructed directly in F-theory. Still the question of the limit depends on the base.

see Cody's talk

- Generically, more flux directions in type IIB compared to F-theory.
- Some F-theory fluxes contain orientifold odd flux components.
- Generically, the demand for a smooth limit removes some matter from the spectrum, in which absence, charge redefinitions uncover more exotic charged singlets.

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