U(1) Symmetries with Higher Charge Singlets in F-Theory and Type IIB

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Plan

- Introduction and motivation
- F-theory in the perturbative type IIB limit
- Morrison-Park at weak coupling
- IIB version of a charge 3 model
- Charge 4 model
- Conclusions and Prospects

Introduction and motivation

- In contrast to $SU(5)$ F-theory GUTs, other MSSM-like realisations in F-th. DO exhibit a weak coupling limit without significant obstructions.

  Lin, Weigand'14'16; Cvetič, Klevers, DM, Oehlmann, Reuter'15;...

- ...we want to explore the weak coupling limit of F-th U(1) models with different singlet spectra:
  - $q = 1, 2$

    Morrison, Park'12;...
  - q up to 3: non-UFD fibers

    Klevers, DM, Oehlmann, Piragua, Reuter'14; Klevers, Taylor'16; Morrison, Park'16; Raghuram'17
  - $q = 4$: UnHiggsing a $U(1) \times U(1)$ model

    Cvetič, Klevers, Piragua, Taylor'15; Raghuram'17

F-theory in the perturbative type IIB limit

Sen'96

Starting with the Weierstrass form

$$y^2 = x^3 + fxz^4 + gz^6\,,$$

make the coord. change $s = x - b_2 z^2/3$. Then the WSF reads

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

with

$$b_4 = f + \frac{b_2^2}{3}\,, \quad b_6 = g - \frac{2}{27} b_2^3 + \frac{2}{3} b_2 b_4\,.$$

setting the scalings $b_2 \to b_2$, $b_4 \to \epsilon b_4$, $b_6 \to \epsilon^2 b_6$.

- 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 $\epsilon \mapsto t\lambda$.

F-theory in the perturbative type IIB limit

- At $\lambda = t = 0$

$$X_3 : \quad \xi^2 = b_2 \, ;$$

  with $\xi = y/sz$. $b_2 = 0$ will be the invariant locus of $\sigma : \xi \to -\xi$ (orientifold locus)

- 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:

$$\Delta_E = \tilde{b}_4^2 - \tilde{b}_2 \tilde{b}_6 = 0 \, .$$

- Discriminant loci permit to read out the gauge symmetries surviving the weak coupling.

Morrison-Park at weak coupling

Consider the the following WSF

Morrison, Park'14

$$y^2 = x^3 + \left(c_1 c_3 - b^2 c_0 - \frac{c_2^2}{3}\right) x + c_0 c_3^2 - \frac{1}{3} c_1 c_2 c_3 + \frac{2}{27} c_2^3 - \frac{2}{3} b^2 c_0 c_2 + \frac{b^2 c_1^2}{4} .$$

Setting the variable $x = x - \frac{1}{3} b_2$ (in the patch $z = 1$),

$$y^2 = x^3 + c_2 x^2 + \left(c_1 c_3 - b^2 c_0\right) x + c_0 c_3^2 - b^2 c_0 c_2 + \frac{b^2 c_1^2}{4} ,$$

with the scalings

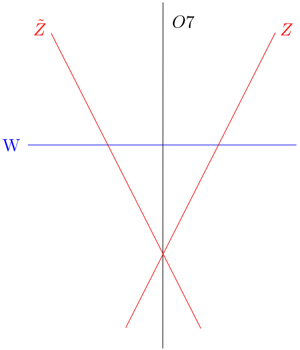
$$b \to \epsilon^0 \, b \,, \qquad c_0 \to \epsilon^2 \, c_0 \,, \qquad c_1 \to \epsilon^1 \, c_1 \,, \qquad c_2 \to \epsilon^0 \, c_2 \,, \qquad c_3 \to \epsilon^0 \, c_3 \,.$$

The weak discriminant reads,

$$\Delta_E = \left(c_3^2 - c_2 b^2\right) \left(\frac{c_1^2}{4} - c_2 c_0\right) .$$

w/ the double cover CY $\xi^2 = c_2$.

Morrison-Park at weak coupling



In the CY, the discriminant splits as

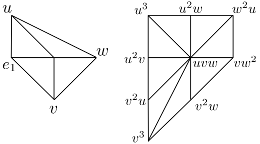
$$\Delta_E = (c_3 - \xi b)\ (c_3 + \xi b)\ \left(\frac{c_1^2}{4} - \xi^2 c_0\right)$$

- A single brane Z at $c_3 - \xi b = 0$ and its image $\tilde{Z}$ at $c_3 + \xi b = 0$, give rise to a U(1) symmetry.
- A Whitney brane W at the invariant locus

$$\frac{c_1^2}{4} - \xi^2 c_0 = 0$$

- Two charged siglets: $q = 1$ at $Z \cap \mathrm{W}$, $q = 2$ at $Z \cap \tilde{Z}$.
- U(1) remains GS massless as $Z_- = Z - \tilde{Z} = 0$

U(1) models with charge 3 singlets



$$p_{F_3} = s_1 u^3 e_1^2 + s_2 u^2 v e_1^2 + s_3 u v^2 e_1^2 + s_4 v^3 e_1^2 + s_5 u^2 w e_1 + s_6 u v w e_1 + s_7 v^2 w e_1 + s_8 u w^2 + s_9 v w^2$$

The fiber $p_{F_3} = 0$ can be mapped to a WSF, with $f(s_i)$ and $g(s_i)$. The WCL can be obtained in the regime

$$s_1 \to \epsilon^1 s_1, \quad s_5 \to \epsilon^1 s_5, \quad s_8 \to \epsilon^1 s_8, \quad s_i \to \epsilon^0 s_i \quad (i \neq 1, 5, 8)\,.$$

CY Equation + Weak discriminant $X_3 \; : \xi^2 = \frac{s_6^2}{4} - s_2 s_9$

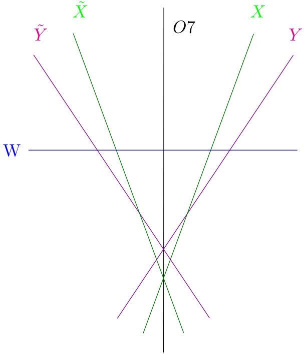
$$\Delta_E = -\frac{1}{4} s_9 \left(-s_3 s_6 s_7 + s_2 s_7^2 + s_3^2 s_9 + s_4(s_6^2 - 4 s_2 s_9)\right)$$
$$\times \left(s_2^2 s_8^2 + s_2(-s_5 s_6 s_8 + s_5^2 s_9 - 2 s_1 s_8 s_9) + s_1(s_6^2 s_8 - s_5 s_6 s_9 + s_1 s_9^2)\right).$$

U(1) models with charge 3 singlets

- We have two D7 branes X, Y and their images ($\tilde{X}$, $\tilde{Y}$) plus a Whitney brane W.
- $Y_- = -2X_-$ implies that the orientifold odd axion coupling leaves a massless U(1) combination.

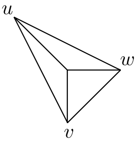
$$Q = 2Q_X + Q_Y \,.$$

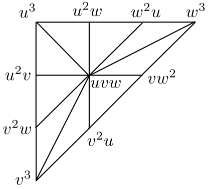
- We find a perfect match between vertical fluxes in F-th. and gauge fluxes in type IIB. Chiralities march perfectly.

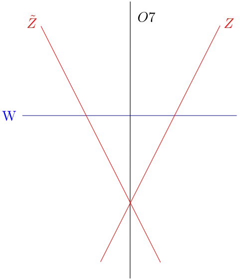


Type IIB	$X\tilde{X}$	$X\tilde{Y}$	$\mathrm{W}X$	$\tilde{Y}Y$	XY	$Y\mathrm{W}$
	~~$\mathbf{1}_{(2,0)}$~~	$\mathbf{1}_{(1,1)}$	$\mathbf{1}_{(-1,0)}$	$\mathbf{1}_{(0,-2)}$	$\mathbf{1}_{(1,-1)}$	$\mathbf{1}_{(0,1)}$
F-theory	-	$\mathbf{1}_3$	$\mathbf{1}_{-2}$		$\mathbf{1}_1$	

Detour: Model with $\mathbb{Z}_3$ discrete symmetry







$$\begin{aligned}\Delta_E = -\frac{1}{4}&\left(-s_3 s_6 s_7 + s_2 s_7^2 + s_3^2 s_9 + s_4(s_6^2 - 4 s_2 s_9)\right)\\ &\times [-s_{10}^2 s_2^3 + s_{10}(s_1 s_6^3 - s_2 s_6(s_5 s_6 + 3 s_1 s_9) + s_2^2(s_6 s_8 + 2 s_5 s_9))\\ &+ s_9(s_2^2 s_8^2 + s_2(-s_5 s_6 s_8 + s_5^2 s_9 - 2 s_1 s_8 s_9) + s_1(s_6^2 s_8 - s_5 s_6 s_9 + s_1 s_9^2))]\,.\end{aligned}$$

- U(1) divisor has an odd part $Z_- = -3X_-$, hence it becomes GS massive.
- D1 instanton charges under the U(1) are $0 \bmod 3$. The $\mathbb{Z}_3$ symmetry is manifest in the instanton sector. Similar argument holds for D3's.

Detour: Model with $\mathbb{Z}_3$ discrete symmetry

- Ideal for the discretely charged singlet in F-theory is generated for 50 non transversally intersecting polynomials. That makes it hard to compute its chirality.
- $\mathbb{Z}_3$ model has two WC limits:

$$s_1 \to \epsilon^1 s_1\,, \quad s_5 \to \epsilon^1 s_5\,, \quad s_8 \to \epsilon^1 s_8\,, \quad s_{10} \to \epsilon^1 s_{10}\ ,$$

  and

$$s_1 \to \epsilon^1 s_1\,, \quad s_2 \to \epsilon^1 s_2\,, \quad s_3 \to \epsilon^1 s_3\,, \quad s_4 \to \epsilon^1 s_4\ ,$$

  chiralities can be computed in both WC limits.

$$\chi(\mathbf{1})_F = \chi(\mathbf{1})_{\text{w.c.}} + a_1 \mathcal{S}_9 \bar{K}_B (2\bar{K}_B - \mathcal{S}_9) = \chi(\mathbf{1})'_{\text{w.c.}} + a_2 \mathcal{S}_7 \bar{K}_B (2\bar{K}_B - \mathcal{S}_7)\ ,$$

- one obtains

$$\chi(\mathbf{1})_F = \Lambda(\mathcal{S}_7 - 2\mathcal{S}_9)(2\mathcal{S}_7 - \mathcal{S}_9)(-3\bar{K}_B + \mathcal{S}_7 + \mathcal{S}_9)\ .$$

  for $G_4 = \frac{\Lambda}{9}\left(3S_{(3)}(3S_{(3)} + 3\bar{K}_B - 2\mathcal{S}_7 - 2\mathcal{S}_9) - 2\mathcal{S}_7^2 + 5\mathcal{S}_7\mathcal{S}_9 - 2\mathcal{S}_9^2\right)$

Charge 4 model

U(1) with $q = 3$, z coord. of the section

Klevers, Taylor'16; Morrison, Park'16

$$\hat{z} = s_7 s_8^2 - s_6 s_8 s_9 + s_5 s_9^2 \,,$$

is singular for $s_8 = s_9 = 0$. Models with higher charges have a non UFD structure.
Charge 4 model: Higgs a $U(1) \times U(1)$ with a vev field $q = (1, -1)$ to $U(1)$.
Model also contains $q = (2, 2)$, so one gets a charge 4 singlet.

Raghuram'16

Fiber Eq.

$$p = u(s_1 u^2 + s_2 uv + s_3 v^2 + s_5 uw + s_6 vw + s_8 w^2) + (a_1 v + b_1 w)(d_0 v^2 + d_1 vw + d_2 w^2) = 0$$

WC limit,

$$s_1 \to \epsilon s_1 \,, \quad s_2 \to \epsilon s_2 \,, \quad s_3 \to \epsilon s_3 \,, \quad d_0 \to \epsilon d_0 \,,$$

Charge 4 model

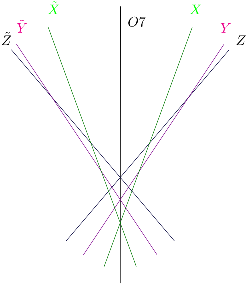
CY threefold eq.

$$\xi^2 = b_2 = \frac{s_6^2}{4} - a_1 d_1 s_5 \,,$$

Weak discriminant

$$\Delta_E = -\frac{1}{16} a_1 \Delta_2 \Delta_3 \,,$$

all factors split. No invariant brane! Two U(1)s become GS massive by couplings to two orientifold odd axions.



F-th. U(1) charge:
$Q = \frac{1}{2}(5Q_X - Q_Y + 3Q_Z)$,

~~$\mathbf{1}_{(2,0,0)}$~~	$\mathbf{1}_{(0,2,0)}$	$\mathbf{1}_{(0,0,2)}$	$\mathbf{1}_{(1,-1,0)}$	$\mathbf{1}_{(1,1,0)}$	$\mathbf{1}_{(1,0,-1)}$	$\mathbf{1}_{(1,0,1)}$	$\mathbf{1}_{(0,-1,-1)}$	$\mathbf{1}_{(0,-1,1)}$
$X\tilde{X}$	$Y\tilde{Y}$	$Z\tilde{Z}$	XY	$X\tilde{Y}$	XZ	$X\tilde{Z}$	YZ	$Y\tilde{Z}$
$-$	-1	3	3	2	1	4	-1	2

Conclusions

- All F-th U(1) models built so far generically have a perturbative IIB version.
- Beyond charge 4?
- What are the brane distribution patterns in IIB that have a propper F-theory uplift?
- How does this extend to 6D? Restrictions on the number of odd axions (odd divisors).

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Dzięki!