NEW RESOLUTIONS FOR F-THEORY & CHIRAL MATTER IN STANDARD MODEL-LIKE CONSTRUCTIONS

upcoming work w/:

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INTRODUCTION

- F-theory on elliptic CY4 is a powerful toolkit for constructing SM-like vacua in string theory.

[Beasley - Heckman - Vafa 0802.3391]
[Donagi - Wijnholt 0802.2969]
[Lin - Weigand 1406.6071, 1604.04292]
[Grassi - Halverson - Shaneson - Taylor 1409.8295]
[Cvetic - Halverson - Lin - Liu - Tian 1903.00009]
[Cvetic - Halverson - Lin - Long 2004.00630]
[Taylor - Turner 1906.11092]
[others]

- Landscape questions → tools to study large families of vacua.
- 4D : G_4 flux needed for chiral matter
- New procedure (synthesis of known techniques) to compute fluxes for large class of hypersurface CY 4-folds (non-toric bases, non-Weierstrass)
- $(SU(3) \times SU(2) \times U(1))/\mathbb{Z}_6$ models

[Raghuram - Taylor - Turner 1912.10991]

PLAN FOR TALK

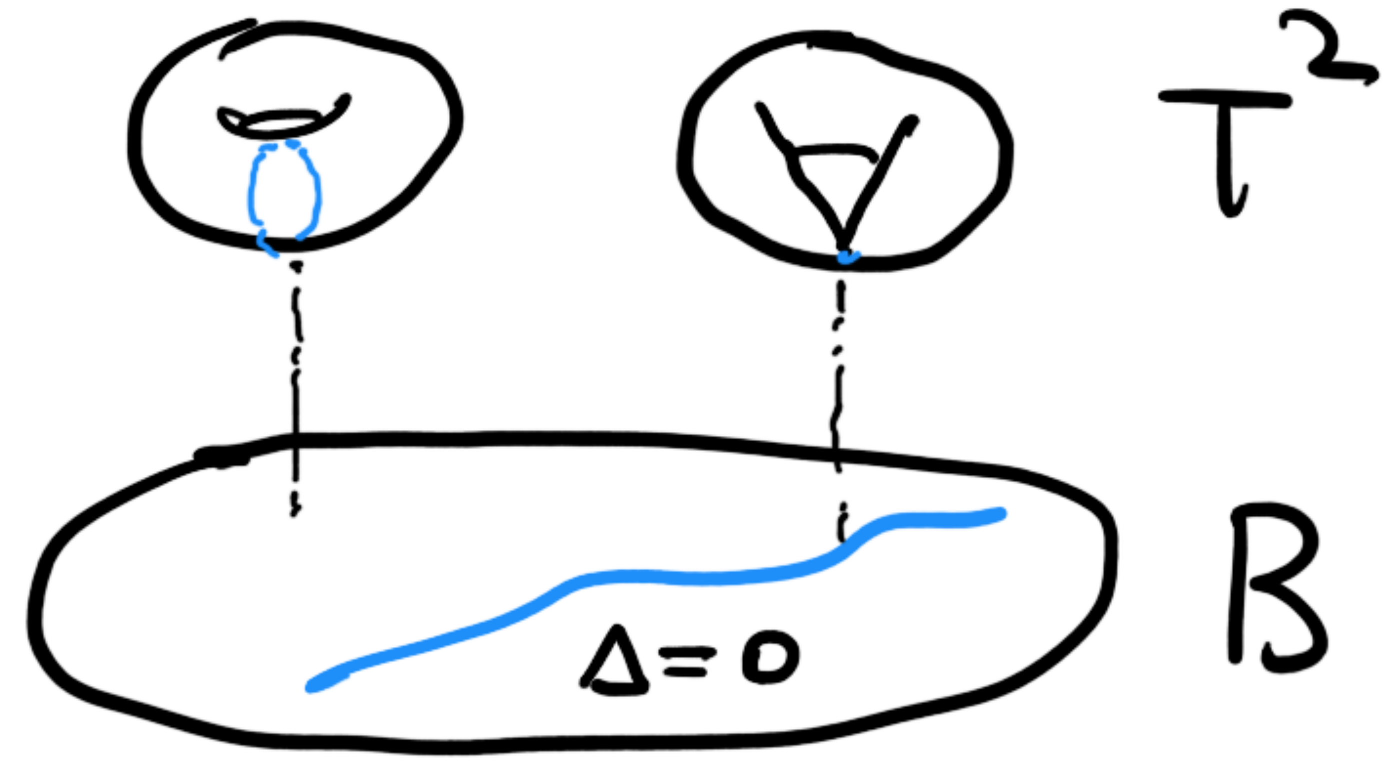
I. Tuned gauge symmetry, generic matter, and $(SU(3) \times SU(2) \times U(1))/\mathbb{Z}_6$

II. Resolving the $(SU(3) \times SU(2) \times U(1))/\mathbb{Z}_6$ model

III. Flux backgrounds for resolved elliptic CY 4-folds

IV. Selected results and future prospects

I. Tuned gauge symmetries, generic matter and $(SU(3)\times SU(2)\times U(1))/\mathbb{Z}_6$



- Singular elliptic CY 4-fold
  $$X=\{zy^2-(x^3+fzx^2+gz^3)=0\}$$

- "Tune" (f,g,Δ) : X with gauge symmetry G.
  Kodaira singularity (local) universal feature.

- When is matter R "generic" ?

- (F-theory / 6D (1,0) SUGRA definition) : For fixed G, # of tensors, R is on branch of moduli space w/ highest dimension.*

[Taylor-Turner 1901.02012]

* assuming small anomaly coeffs.

Tuned $(SU(3)\times SU(2)\times U(1))/\mathbb{Z}_6$ model

- MSSM generic for SM group w/ discrete quotient

[Taylor-Turner 1906.11092]

- Characteristic data : $(K_B, \overset{su(2)}{\Sigma_2}, \overset{su(3)}{\Sigma_3}, Y)$

- Constructions: unHiggs $q=4$ $U(1)$ model [Raghuram 1711.03210]
  field theory, Higgs $SU(4)\times SU(3)\times SU(2)$ on $(4,1,\bar{2}), (1,3,\bar{2})$
  [Taylor-Turner-Raghuram 1912.10991]
  $Y=0$, F_{11} toric hypersurface
  [Klevers-Peña-Oehlmann-Piragua-Reuter 1408.4808]

- $R = R_{MSSM} \oplus R_{exotic} \oplus R_{adjoint}$

$$R_{MSSM} = (3,2)_{1/6} \oplus (3,1)_{-1/3} \oplus (3,1)_{2/3} \oplus (1,2)_{1/2} \oplus (1,1)_1$$

$$\boxed{R_{exotic} = (3,1)_{-4/3} \oplus (1,2)_{3/2} \oplus (1,1)_2}$$

II. Resolution : Cubic in $\mathbb{P}^2_{[u:v:w]}$

- $q=4$ model, un Higgs $\quad a_1 = s_3 = 0$

$$X = \left\{ u\left(s_1 u^2 + s_2 uv + s_3 v^2 + s_5 uw + s_6 vw + s_8 w^2\right) + (a_1 v + b_1 w)(d_0 v^2 + d_1 vw + d_2 w^2) = 0 \right\}$$

- Hypersurface in $Y : \mathbb{P}(\mathcal{L}_u \oplus \mathcal{L}_v \oplus \mathcal{L}_w) \to B$

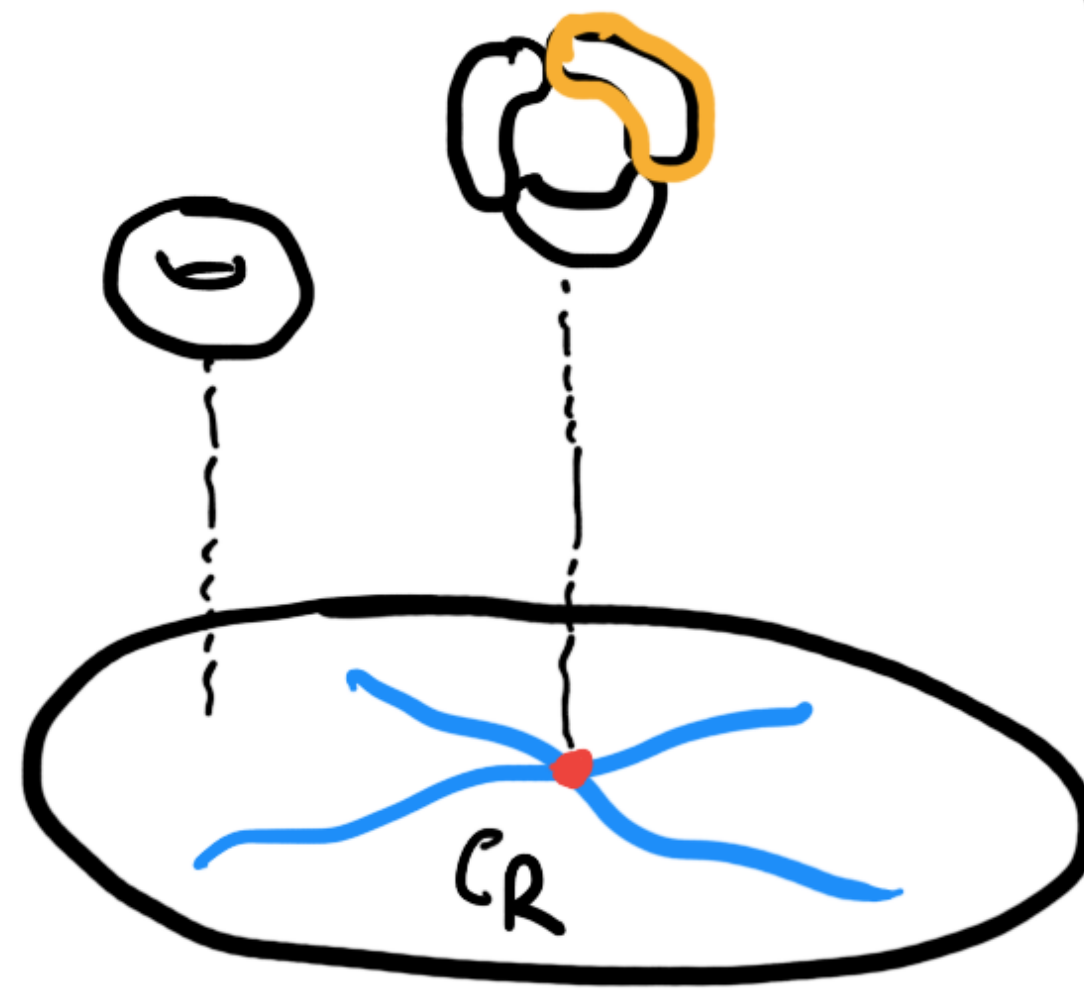
$$[\mathcal{L}_u] = \Sigma_3 - Y, \quad [\mathcal{L}_v] = -K_B - \Sigma_2 - Y, \quad [\mathcal{L}_w] = -K_B + \Sigma_3$$

- Resolution $\quad X_5 \xrightarrow{\varphi} B$, five blowups

- Rational (not holomorphic) zero, generating sections

$$\hat{D}_0, \quad \hat{D}_1, \quad \varphi_*(\hat{D}_1 \cdot \hat{D}_0) = Y$$

III. Flux background for resolved CY4 $\tilde{X}$



- Local matter, $C_R = [\{\Delta_i = \Delta_j = 0\}]$

- Chiral index, $\chi(R) = \int_{C_R} G_4, \quad G_4 \in H^4(\tilde{X})$

[for review cf. Weigand 1806.01854]

- $H^{2,2}_{ver} = \text{span}\left(H^{1,1} \wedge H^{1,1}\right), \quad H^{1,1} = \text{span}\{\hat{D}_{I = A, \alpha, i}\}$

- $\chi(R) = C_R^{IJ} \, Ⓗ_{IJ} = C_R^{IJ} \, \hat{G} \cdot \hat{D}_I \cdot \hat{D}_J$

- Unbroken Poincaré $\times$ gauge $\Rightarrow Ⓗ_{\alpha I} = Ⓗ_{\alpha\beta} = 0$.

[Dasgupta-Rajesh-Sethi 9908088]
[Grimm-Hayashi 1111.1232]
[Cvetič-Grimm-Klevers 1210.6034]

$$\Rightarrow \boxed{\begin{aligned} Ⓗ_{IJ} &= G^{KL} \, \bar{\Omega}_{IJKL} + \Theta_{IJ} \\ \bar{\Omega}_{IJKL} &= \hat{D}_I \cdot \hat{D}_J \cdot \hat{D}_K \cdot \hat{D}_L - W_{0IJ} \cdot W_{KL} - W_{IJ} \cdot W_{0KL} + W_{00} \cdot W_{IJ} \cdot W_{KL} \\ &\quad - \left(W_{IJ, i_S} \, h^{i_S j_S'}\right) \cdot W_{KL j_S'} \quad \text{for } \tilde{X} \text{ elliptic w/ generating section} \end{aligned}}$$

[PJ - Taylor - Turner, to appear]

Flux background & intersection theory

- Θ_{IJ} computable via intersection numbers $\hat{D}_I \cdot \hat{D}_J \cdot \hat{D}_K \cdot \hat{D}_L$

- For resolution $\tilde{X} \to X$, X hypersurface of $\mathbb{P}(\bigoplus_i \mathcal{L}_i) \to B$,
  push forward $\varphi_*(\hat{D}_I \cdot \hat{D}_J \cdot \hat{D}_K \cdot \hat{D}_L)$ to Chow ring of B

- Theorem: Given $\mathcal{L}_i \to B$, $\mathbb{P}(\bigoplus_{i=1}^{3} \mathcal{L}_i) \xrightarrow{\pi} B$,
  formal power series $\tilde{Q}(t) = \sum_a \pi^* Q_a t^a$, $Q(t) = \sum_a Q_a t^a$

[Esole - PJ - Kang 1703.00905]

$$\boxed{\pi_* \tilde{Q}(H) = \sum_{i=1}^{3} \frac{Q([\mathcal{L}_i])}{\prod_{j \neq i}([\mathcal{L}_i] - [\mathcal{L}_j])}}, \quad H \equiv c_1(\mathcal{O}_{\mathbb{P}^2})$$

[PJ - Taylor - Turner, to appear]

- Similar theorem for exceptional divisors $Y_i \xrightarrow{\hat{E}_i \to 0} Y_{i-1}$

[Esole - PJ - Kang 1703.00905]
[Aluffi 0809.2425]

3D Chern-Simons Terms & 4D Anomalies

- 1-loop CS terms in 3D KK theory:

$$\Theta^{3D}_{IJ} = \sum_R b_{IJ}(R)\, \chi(R) = \Theta^{\text{M-theory}}_{IJ}$$

[Grimm-Hayashi 1111.1232]
[Cvetič-Grimm-Klevers 1210.6034]
[Grimm-Savelli 1109.3191]
[Corvilain-Grimm-Regalado 1710.07626]

- Anomalies (GS mechanism):

$$A^{IJ}_a \Theta_{IJ} = 0 \iff \boxed{\begin{array}{l} \bar{M} \quad \text{defined by } \vec{e}_{IJ}\cdot\bar{M}\cdot\vec{e}_{KL} = \hat{D}_I \hat{D}_J \hat{D}_K \hat{D}_L \\ \text{rank}(\bar{M}) \longleftrightarrow \#\text{ anomaly sol'ns} \end{array}}$$

[PJ-Taylor-Turner, to appear]

- Matching w/ f.t., get invertible linear system, can solve for

$$\boxed{\chi(R) = \chi^{IJ}(R)\, \Theta_{IJ}}$$

- Rational zero section $\hat{D}_0 \Rightarrow m_{KK} \leq m_{W,\,\text{Coulomb}}$ [Grimm-Kapfer-Keitel 1305.1929]

so contributions from KK modes needed for Θ^{3D}_{IJ}.

IV. Selected results

[PJ–Taylor–Turner, to appear]

- Example: $SU(5)$ Tate model, $R = 10 \oplus \bar{5}$

$$\boxed{\chi(5) = \chi(10) = \frac{\alpha}{5} K_B \cdot (6K_B + 5\Sigma) \cdot \Sigma}$$

for any smooth B, $su(5)$ divisor $\Sigma \subset B$

- $(SU(3) \times SU(2) \times U(1))/\mathbb{Z}_6$

MSSM + exotic matter not in Swampland

No obvious constraints on chirality, pending further analysis.

$Y = 0$ results agree with F_{11} model results

Future prospects

- Other SM-like constructions (flux-broken G?)
- Superpotentials
- More general flux backgrounds ($G_4 \in H^{2,2}_{\text{rem}}, H^{2,2}_{\text{hor}}$, flat C_3 configurations)
- More general resolutions, arbitrary dimension

THANK YOU!