F-theory at order α'^3

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Based on work with:

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In this talk...

- I discuss quantum corrections (in g_s and α'). Need control over them to understand vacuum structure of string theory & its EFT.

- Here I focus on the Type IIB corner of the string landscape:

  - $\exists$ efficient probe into the strong g_s regime → F-theory; [Vafa `96]

  - Great arena for particle physics (GUT);

[Donagi, Wijnholt; Beasley, Heckman, Vafa `08]

  - Robust paradigm of moduli stabilization (LVS).

[Balasubramanian, Berglund, Conlon, Quevedo `05]

- Final target is the 4D, N=1 EFT of Type IIB on CY_3 with D7/O7:

  - Corrections to effective Kähler potential are poorly understood.

  - They play a key role in the phenomenology of these vacua.

α' corrections

- Most notable example: $O(\alpha'^3)$ correction to CY_3 volume:

$$K = -2\log\left(\mathcal{V}_3 - \frac{\zeta(3)\,\chi(\mathrm{CY}_3)}{32\pi^3\, g_s^{3/2}}\right)$$

  - Due to closed strings ⇒ N=2 sector; [Antoniadis, Ferrara, Minasian, Narain `97]

  - Shown to survive orientifolding N=2 → N=1. [Becker, Becker, Haack, Louis `02]

- Main aim: Study possible, genuinely N=1 modifications of CY_3 volume.

- Use F-theory because:

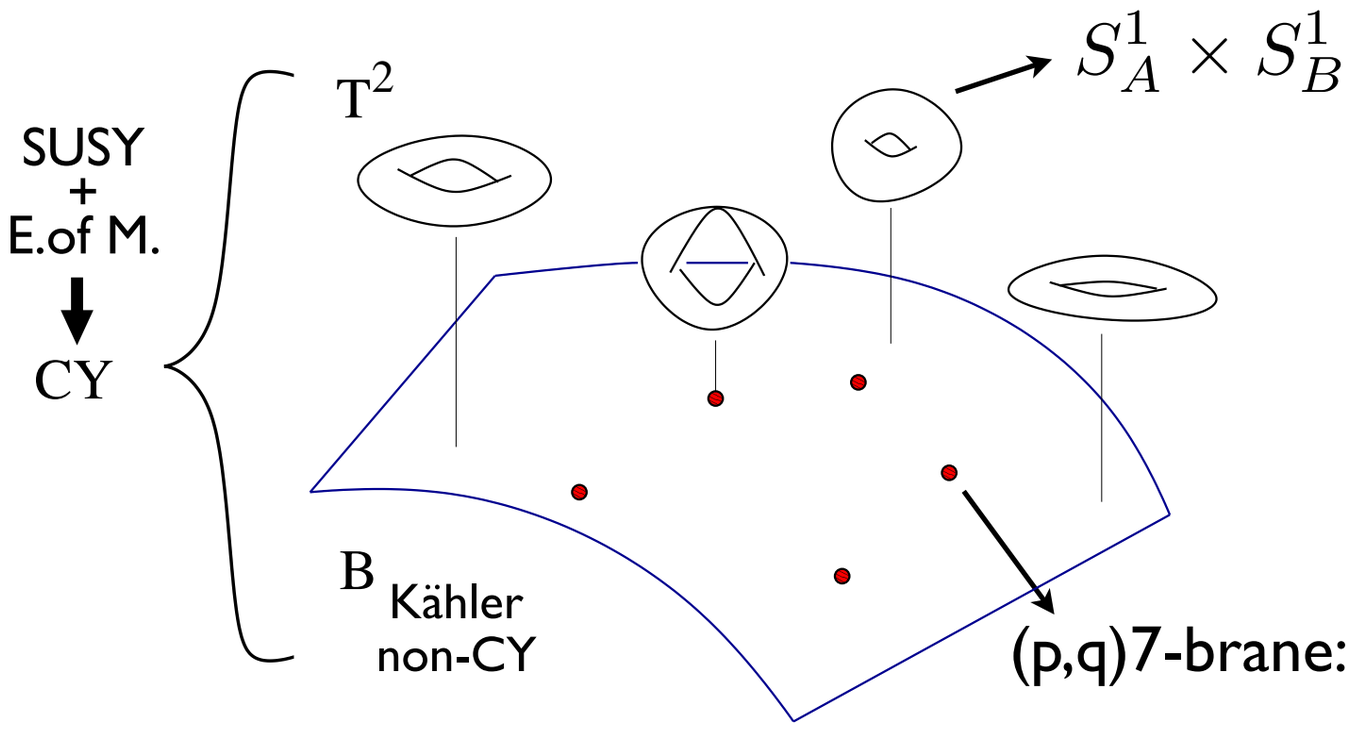
  - It "geometrizes" all g_s effects of Type IIB, and it only needs to be corrected in α';

  - It includes open string effects, through 7-brane backreaction.

F-theory

12D theory: Auxiliary T^2 fibered over the 10D string space

T^2 cplx-str = axio-dilaton $\tau = C_0 + ie^{-\phi}$ varies holomorphically with $\mathrm{SL}(2,\mathbb{Z})$ transitions



Torus size is not physical!

Bookkeeping device of 7-brane backreaction

(p,q)7-brane: divisor on which $pS^1_A + qS^1_B$ collapses

No fundamental description available: $\nexists$ (1,11) sugra.

Yet, in 12D we can encode $\mathrm{SL}(2,\mathbb{Z})$-invariant 10D structures.

Two derivatives

- Let's warm up with $O\,(\alpha'^0)$.

  - Start with the 12D Ricci scalar, integrated on 10D subspace.

$$S_0^{(12)} \sim \frac{1}{l_s^8}\int R_{\rm sc}^{(12)} *_{10} 1 \quad \xrightarrow[\text{red.}]{T^2} \quad S_0^{(10)} \sim \frac{1}{l_s^8}\int \left(R_{\rm sc}^{(10)} - 2\,P\cdot\bar{P}\right) *_{10} 1$$

KK-reduction using the T^2 metric $\frac{1}{\mathrm{Im}\,\tau}\begin{pmatrix} 1 & \mathrm{Re}\,\tau \\ \mathrm{Re}\,\tau & |\tau|^2 \end{pmatrix}$

P is the $U(1)_R$ -covariant quantity $P = \frac{i}{2\,\mathrm{Im}\,\tau}\nabla\tau$ of charge 2.

- $U(1)_R$-invariance + 10D diff-invariance ⇒ "12D diff-invariance"

- Warning : No 12D lift of the 10D measure !

Eight derivatives

- Richer kinematics and non-trivial dynamics.

- T^2 reduction of $S_3^{(12)} \sim \frac{1}{l_s^2}\int [t_8 t_8 + \frac{1}{96}\epsilon_{12}\epsilon_{12}]\,(R^{(12)})^4 *_{10} 1$

  ➡ get a bunch of U(1)$_R$-invariant couplings, in terms of $R^{(10)}$, P & DP.

- Check ? Possible at 4pt level ! Result known from tree-level string amplitudes: [Policastro, Tsimpis `06 -`08]

$$S_3^{(10)}\,|_{4\text{pt}} \sim \frac{1}{l_s^2}\int \left\{ t_8 t_8 \left[(R^{(10)})^4 + 24\,(R^{(10)})^2\,|DP|^2 \right] + \widehat{\mathcal{O}}_1\left[(|DP|^2)^2 \right] \right\} *_{10} 1$$

✓ perfect match!

- Beyond 4pt, we have a prediction for 10D couplings in R & τ .

  ➡ from 12D we only get SL(2,Z)-invariant kinematical structures.

Beyond tree-level

- Account for string dynamics, by either:
  - Loops of 11D KK-modes on a zero-size T^2. [Green, Gutperle, Vanhove `97]
  - SUSY + SL(2,Z)-invariance. [Pioline `98]

$$\Rightarrow \quad S_3^{(12)} = \frac{1}{(2\pi)^7 \cdot 3 \cdot 2^{11} \cdot l_s^2} \int f_0(\tau,\bar{\tau}) \left[t_8 t_8 + \tfrac{1}{96} \epsilon_{12} \epsilon_{12} \right] (R^{(12)})^4 *_{10} 1$$

- For $(\mathrm{Im}\,\tau)^{-1} = g_s << 1$: $f_0(\tau,\bar{\tau}) \approx \underbrace{\frac{2\zeta(3)}{g_s^{3/2}}}_{\mathrm{tree-level}} + \underbrace{\frac{2\pi}{3} g_s^{1/2}}_{1-\mathrm{loop}} + \underbrace{\mathcal{O}(e^{-1/g_s})}_{\mathrm{D}(-1)}$

- Beyond 4pt, SL(2)-charged kinematical structure are not excluded!
  - $f_k(\tau,\bar{\tau}) \cdot \Phi^{(2k)}$ R(f_k)=-2k. E.g. $f_1 R^2 |P|^2 DP + c.c.$ [Kehagias, Partouche `97]
  - May all be related to neutral terms, since $D f_k = a_k f_{k+1} P + b_k f_{k-1} \bar{P}$.

4D N=1 compactifications

- Reduce F-theory on smooth CY_4, elliptically fibered over B_3, with zero-section: $B_3 \rightarrow CY_4$.

  - Two-derivative action yields classical volume of base:

$$S_0^{(4)} = \frac{1}{2\pi\alpha'} \int \mathcal{V}_b \, R_{\rm sc}^{(4)} \; *_4 1$$

  - Eight-derivative action leads to the correction:

$$\boxed{S_{0+3}^{(4)} = \frac{1}{2\pi\alpha'} \int \left(\mathcal{V}_b - \frac{1}{64\pi^3} \int_{\rm B_3} f_0(\tau,\bar\tau)\, c_3({\rm CY}_4)|_{\rm B_3} \right) R_{\rm sc}^{(4)} \; *_4 1}$$

- For constant τ $\Rightarrow$ old N=2 correction ($B_3 = CY_3$);
- N=1 vacua: Correction is non-topological (τ varies over B_3);
- Weyl rescaling induces correction to 4D, N=1 Kähler potential.

Weak coupling

- Correction simplifies when going to weak string coupling.

  - Sen (`97): Restrict CY_4-cplx structure s.t. $g_s \to 0$ is well-defined.

➡ Type IIB on $CY_3 \to B_3$ branched double cover.

➡ O7-plane wrapped on branching locus: In cohomology $D_{O7} = c_1(B_3)$.

$$\tilde{\mathcal{V}}_3 = \mathcal{V}_3 \; - \; \frac{\zeta(3)}{32\pi^3\, g_s^{3/2}} \left(\chi(\mathrm{CY}_3) + 2 \int_{\mathrm{CY}_3} D_{\mathrm{O7}}^3 \right) \quad + \quad \mathcal{O}(g_s^{-1/2})$$

- Topological correction at closed-string tree-level.
- Next-to-leading: tree-level of open + unorientable strings.
- Arises from graviton two-point function in orientifold backgrounds.
- Hard to see in toroidal models.

Caveats / Open questions

- Our 12D $O(\alpha'^3)$ action is only checked at 4pt!
  - Test it beyond 4pt : derive 10D EFT from amplitudes or 11D loops.
- Employ 12D logic to study the F_3 / H_3 -flux sector in 10D at $O(\alpha'^3)$.
- Correction to Weyl rescaling does not fully determine Kähler potential!
  - Derive corrections to kinetic terms of moduli. [Berg, Haack, Kang, Sjörs `14]
- Include corrections to the vacuum solution, such as warping effects.
  [Grimm, Pugh, Weissenbacher `14] ; [Martucci `14]
- Our correction persists on singular CY_4! Are there more? [Junghans, Shiu`14]
- Study impact on 4D scalar potential. [Ciupke, Louis, Westphal `15]