F-theory at order α'^3

Raffaele Savelli

IPhT - CEA/Saclay

DESY Theory Workshop

Hamburg, September 30, 2015

Based on work with:

R. Minasian and T. Pugh

arXiv:1506.06756

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 $\to$ F-theory; [Vafa `96]

  - All distinctive features of GUT models can be accommodated; [Donagi, Wijnholt; Beasley, Heckman, Vafa `08]

  - One has the Large Volume Scenario as promising paradigm of moduli stabilization. [Balasubramanian, Berglund, Conlon, Quevedo `05]

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

  - Knowledge of quantum corrections is still very limited, especially for the effective Kähler potential.

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

Context

- Most notable example is a certain $\mathcal{O}\left(\alpha'^3\right)$ correction to the 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 $\Rightarrow$ N=2 sector; [Antoniadis, Ferrara, Minasian, Narain `97]
  - Shown to survive orientifolding N=2 → N=1. [Becker, Becker, Haack, Louis `02]

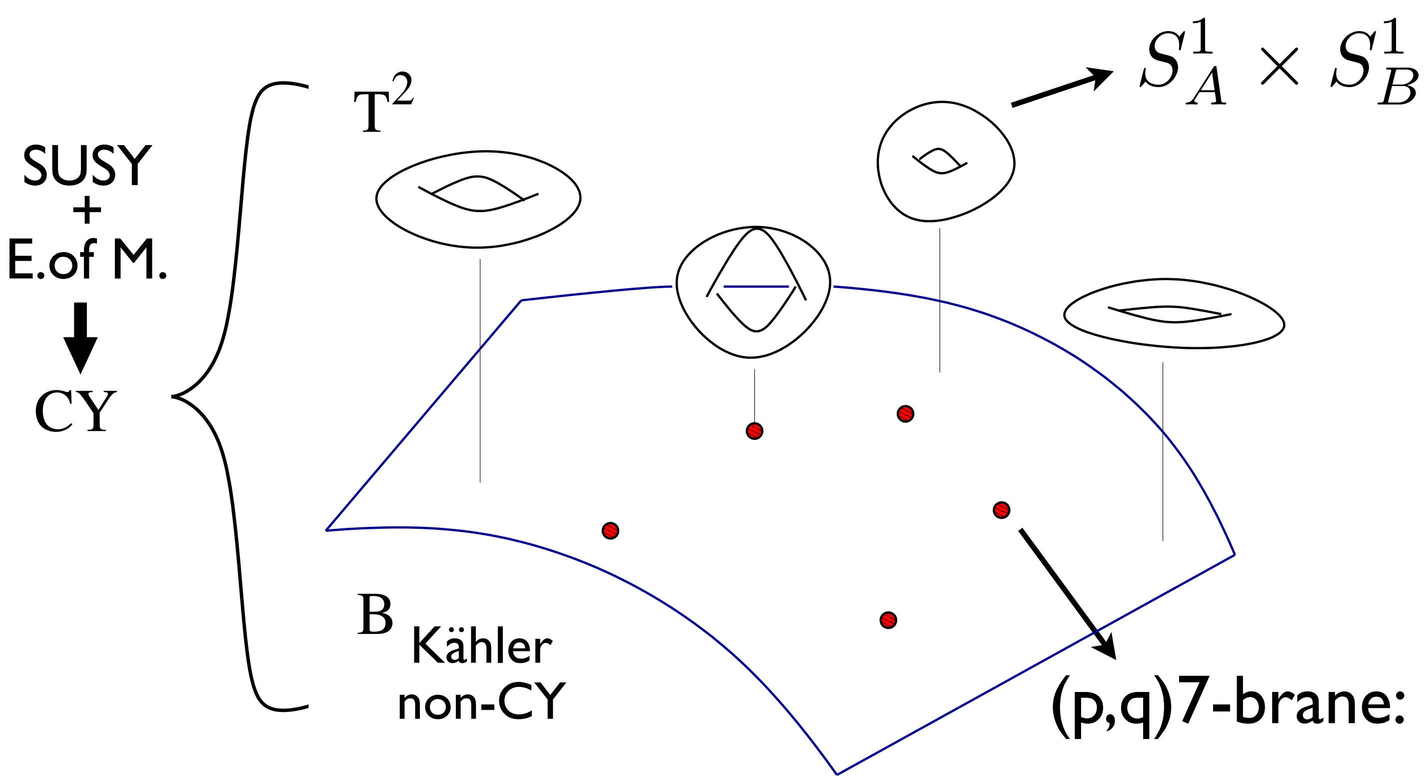
- Main aim: Study possible, genuinely N=1 modifications of CY_3 volume.

- Using F-theory is convenient, as:
  - 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 $SL(2,\mathbb{Z})$ transitions



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

Torus size is not physical!
Bookkeeping device of
7-brane backreaction

$\nexists$ fundamental description (yet): $\nexists$ (1,11) sugra.

Still, 12D are able to encode $SL(2,\mathbb{Z})$-invariant 10D structures.

Two derivatives

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

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

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

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

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

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

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

Eight derivatives

- At $\mathcal{O}(\alpha'^3)$ we have non-trivial string dynamics.

  - Start with the "12D" action:

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

  ‣ f_0 holds all g_s corrections compatible with SUSY + SL(2)-invariance.

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

  - Reduction on T^2 $\Rightarrow$ complicated sum of $U(1)_R$-invariant couplings, written in terms of $R^{(10)}$, P and DP.

  - Perfect match with known 4pt , tree-level result. [Policastro, Tsimpis `06 - `08]

  - Prediction of 10D couplings of R & τ beyond 4pt.

4D N=1 compactifications

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

  - Eight-derivative action yields correction to volume of base:

$$\boxed{S^{(4)}_{0+3} = \frac{1}{2\pi\alpha'}\int\left(\mathcal{V}_b - \frac{1}{64\pi^3}\int_{\mathrm{B}_3} f_0(\tau,\bar{\tau})\, c_3(\mathrm{CY}_4)|_{\mathrm{B}_3}\right) R^{(4)}_{\mathrm{sc}} \, *_4 1}$$

  - 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 -complex structure s.t. $g_s \rightarrow 0$ is well-defined.

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

➡ O7-plane wrapping branch locus: In cohomology $D_{O7} = c_1(B_3)$.

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

- 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.
- Absent in toroidal models!

Caveats / Open questions

- Our 12D $\mathcal{O}\left(\alpha'^3\right)$ action is only checked at 4pt!
    - Test it beyond 4pt : 5pt amplitude computation or M/F duality.
- Employ 12D logic to study the F_3 / H_3 -flux sector in 10D at $\mathcal{O}\left(\alpha'^3\right)$.
- 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 the 4D scalar potential. [Ciupke, Louis, Westphal `15]