Non-perturbative effects on seven-brane Yukawa couplings

Fernando Marchesano

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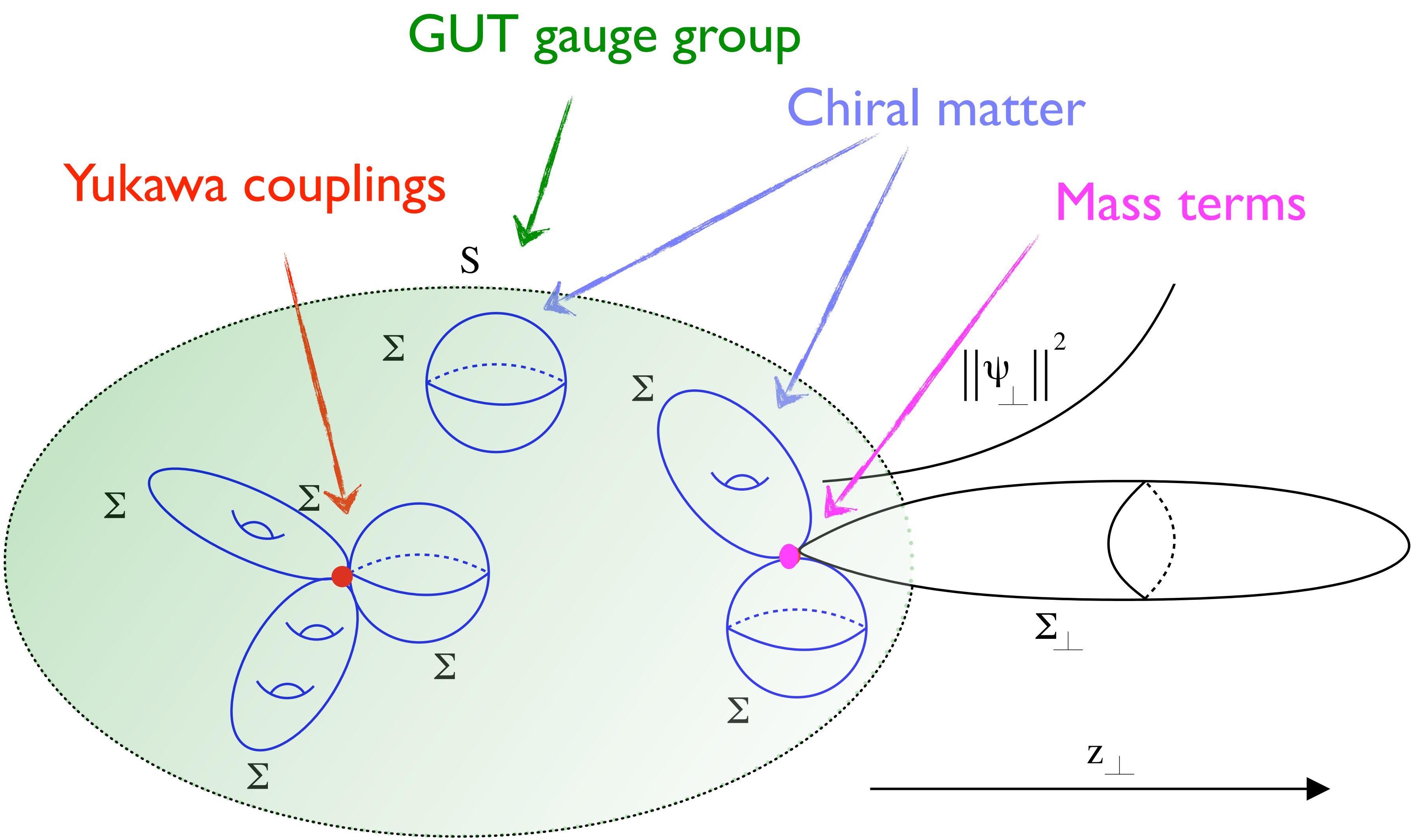
In collaboration with
Luca Martucci

arXiv: 0910.5496

Motivation: GUT's from F-theory

- F-theory GUT local models have recently attracted a lot of attention, and shown to contain a number of phenomenological virtues



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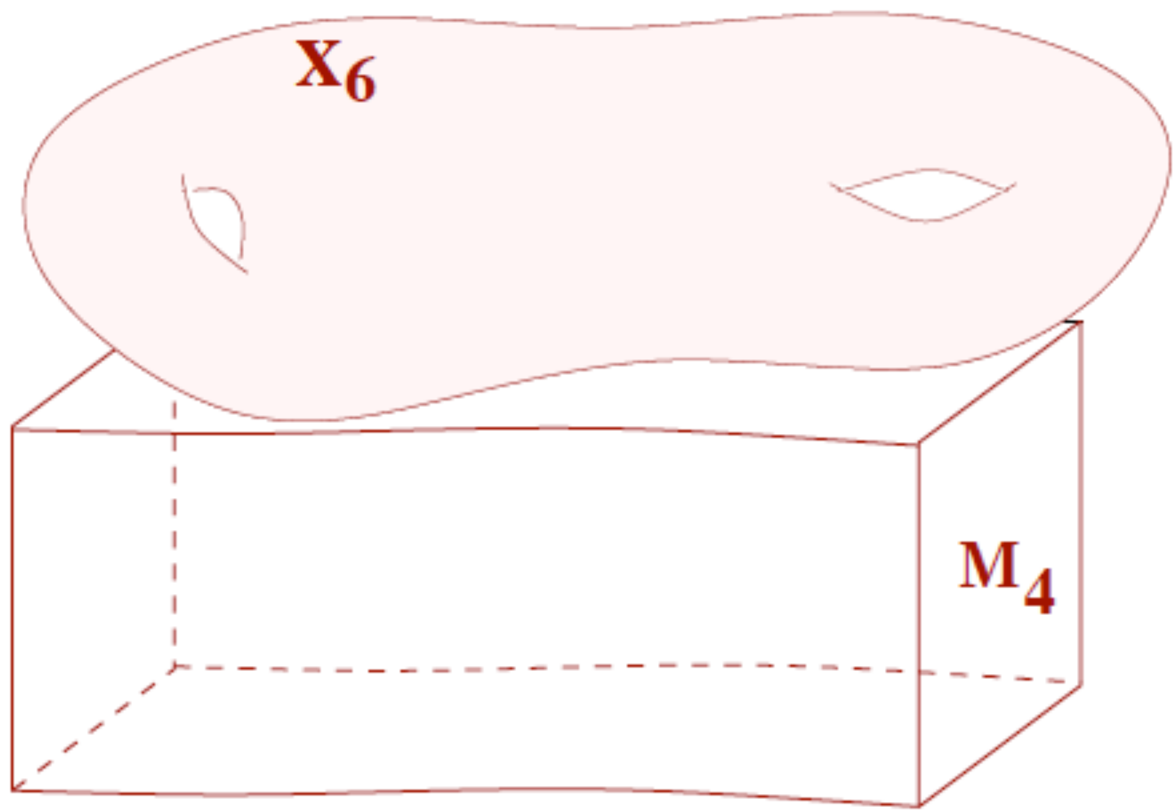
- F-theory: type IIB sugra



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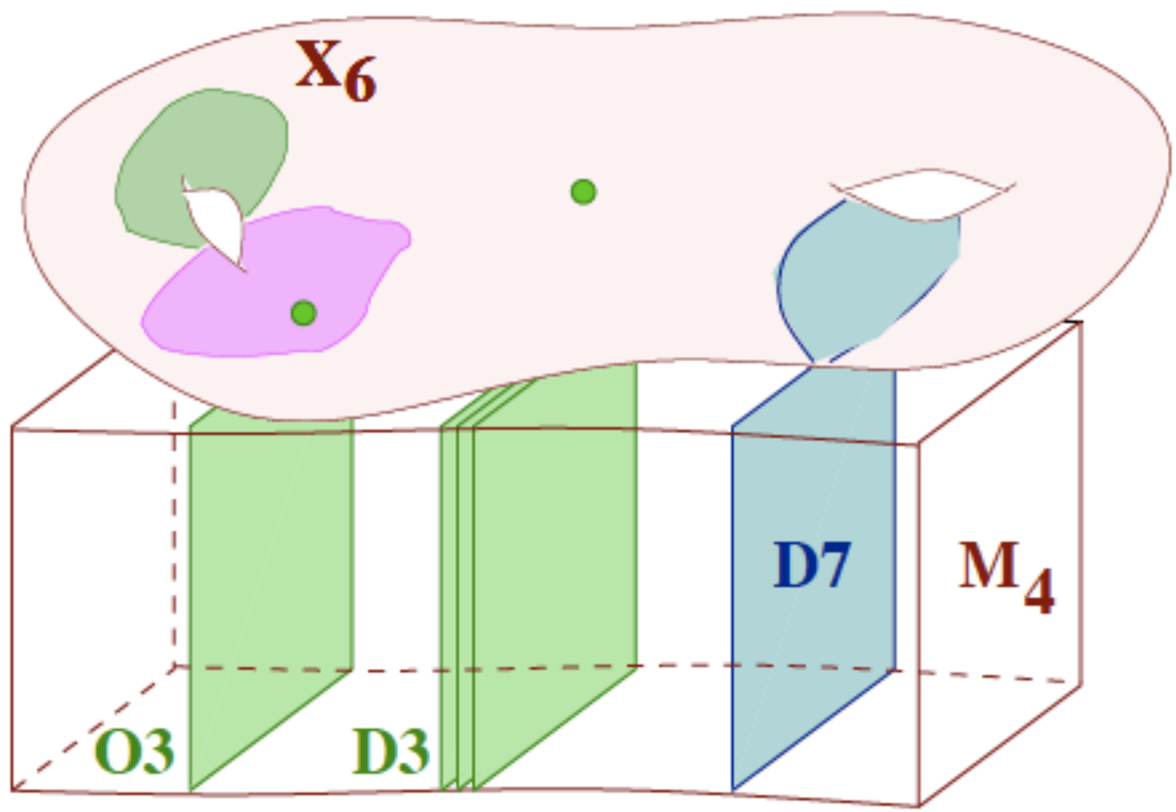
- F-theory: type IIB sugra + localized objects



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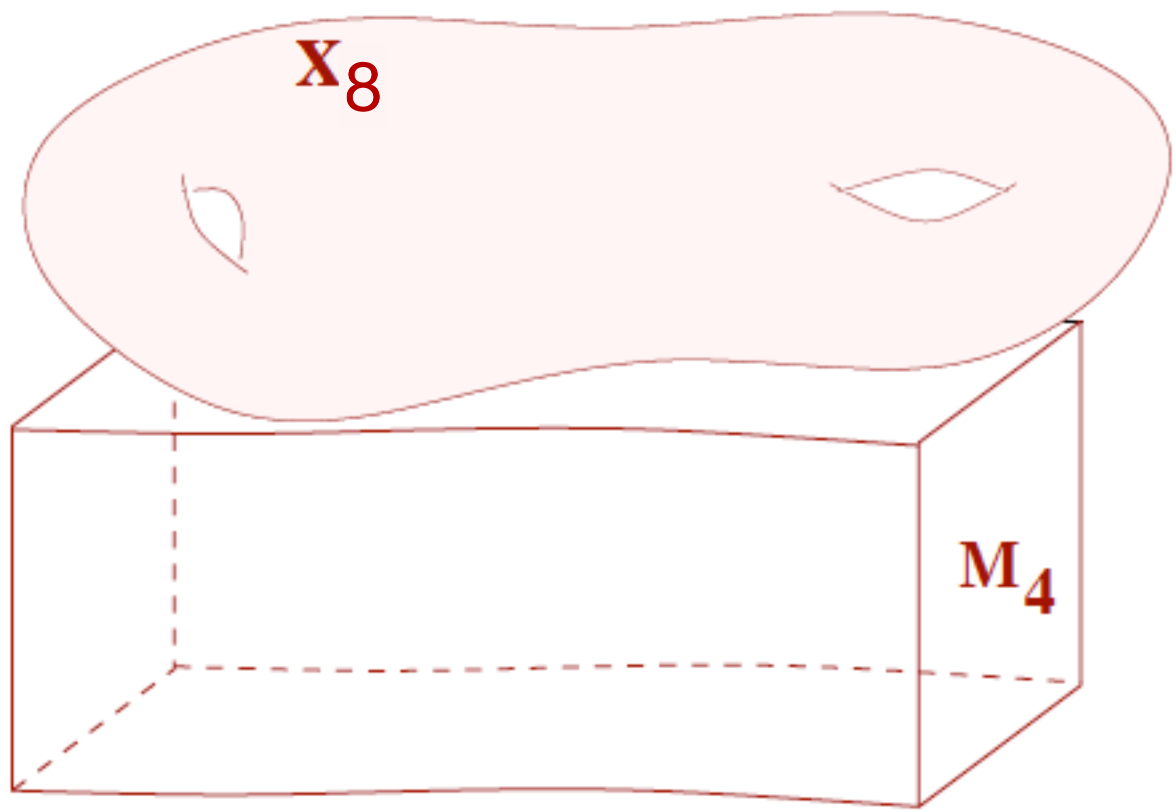
- F-theory: type IIB sugra + loc. sources → geometry (strong coupling)



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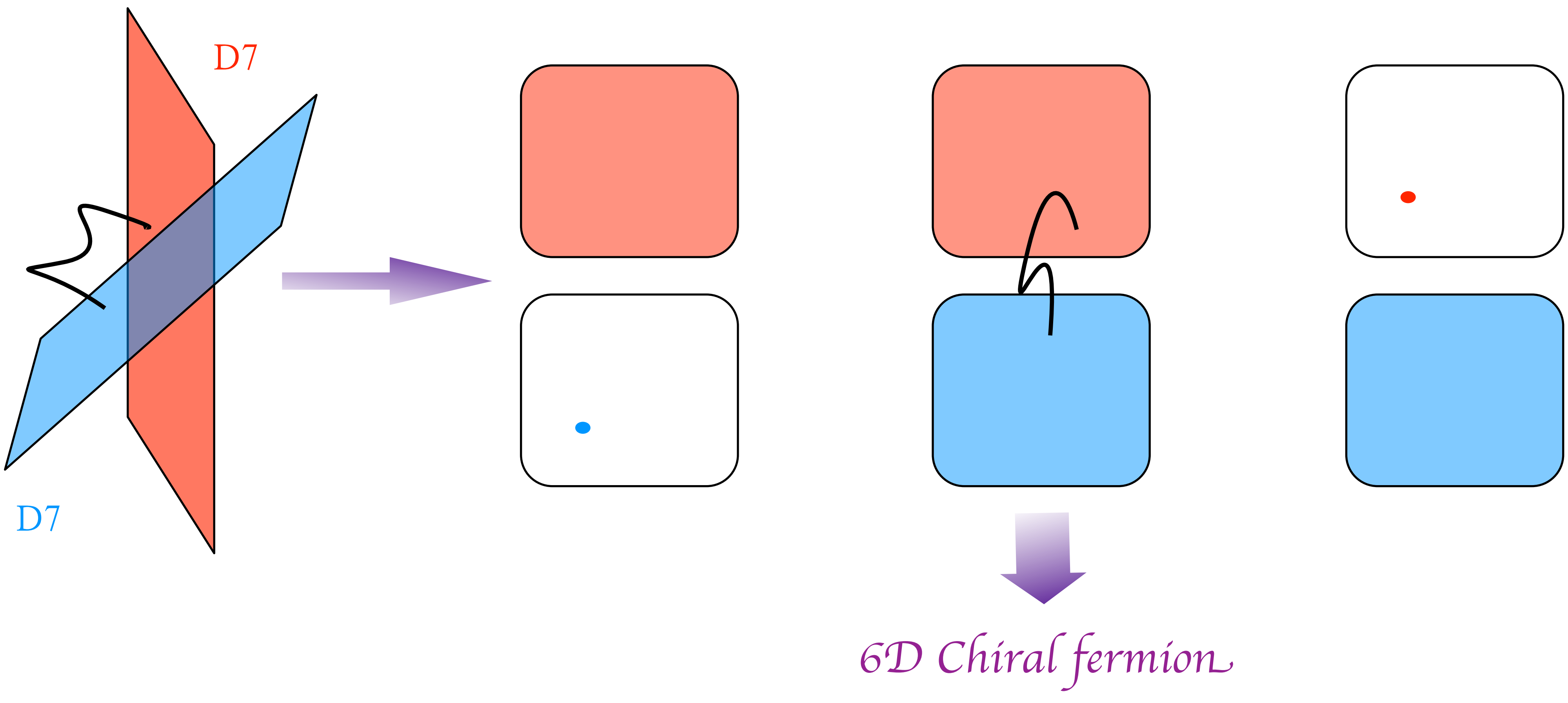
- One can understand their main features in terms of type IIB models

  - 4d Chirality



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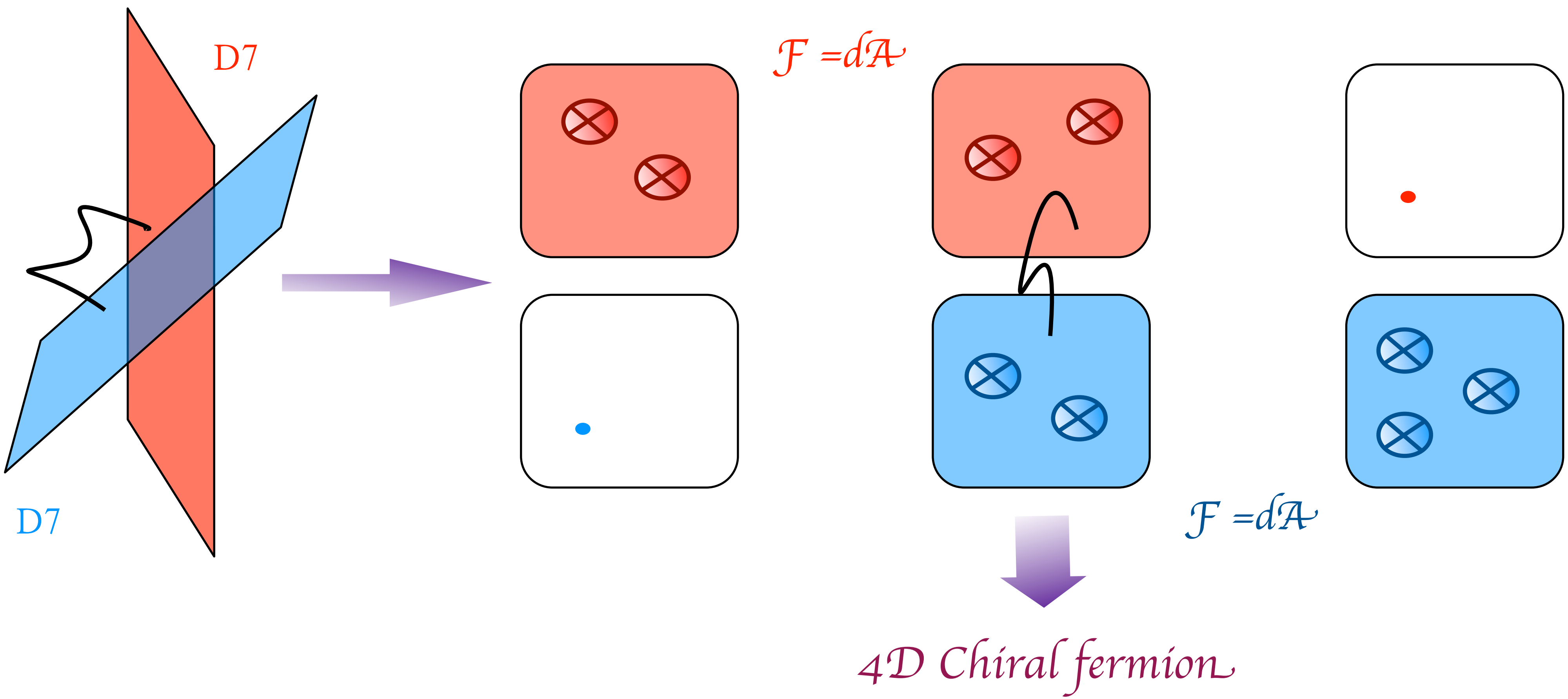

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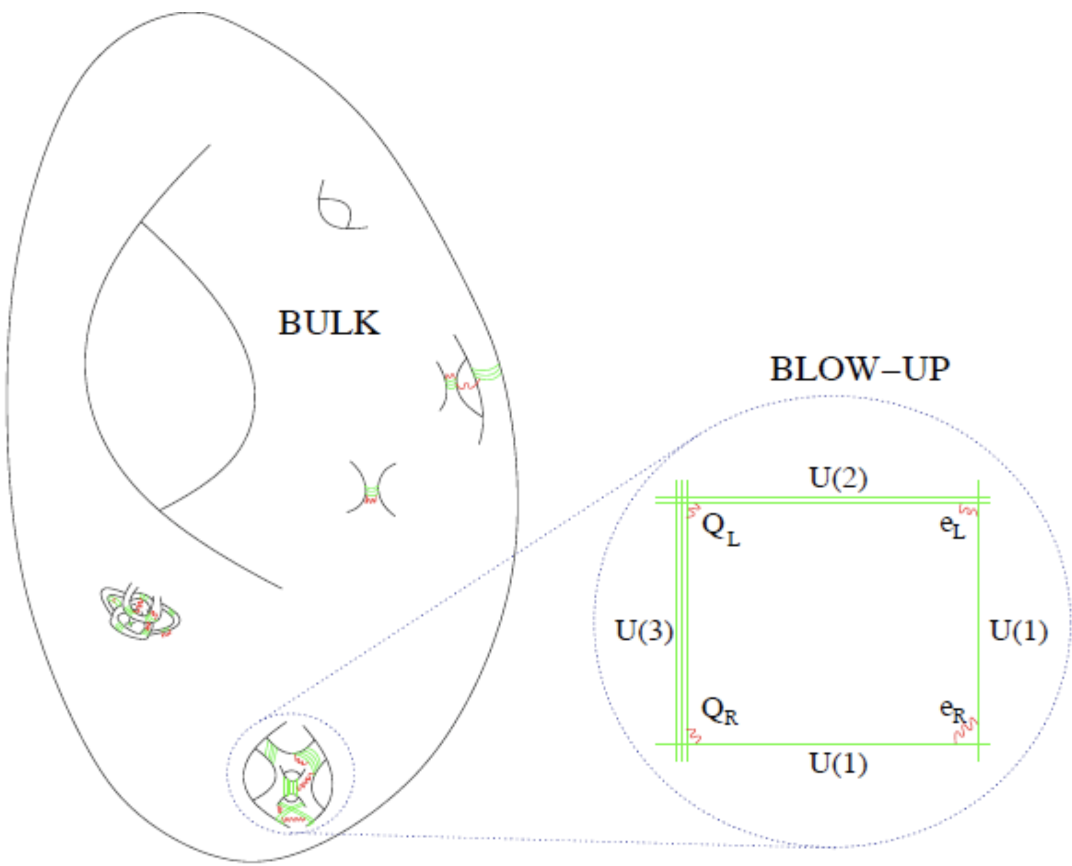
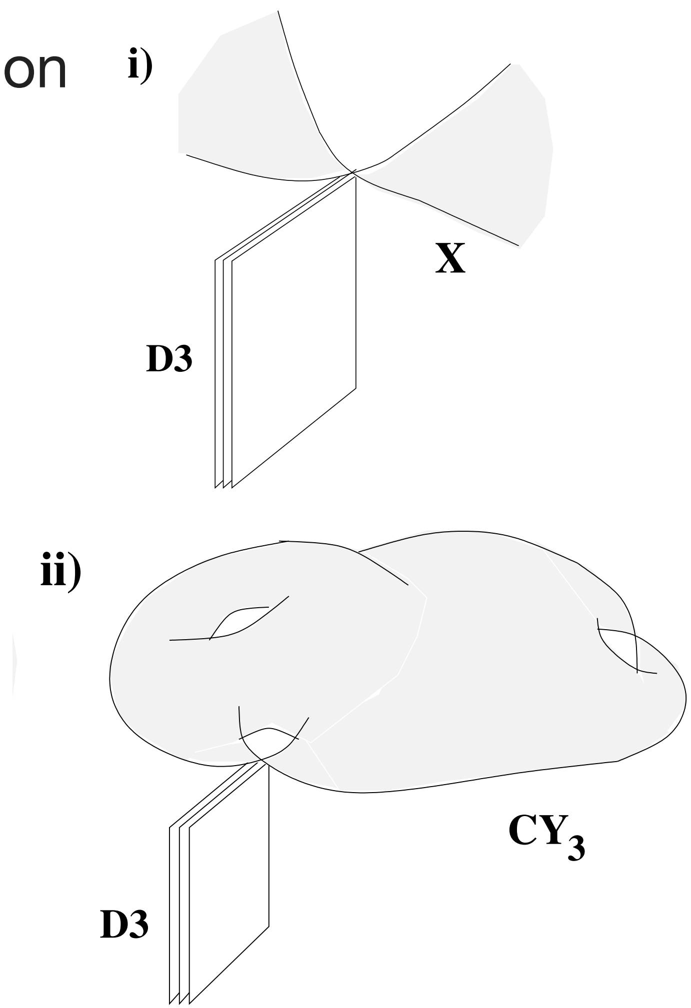
  - Local Models → gauge coupling unification





Motivation: GUT's from F-theory

- F-theory GUT local models have recently attracted a lot of attention, and shown to contain a number of phenomenological virtues
- One can understand their main features in terms of type IIB models
- The main new ingredients in F-theory w.r.t. type IIB models are
  - D7-branes → (p,q) 7-branes
  - U(N) gauge group → U(N), SO(N), $E_{6,7,8}$ gauge group

F-theory can combine :

- GUT's (heterotic)
- Local models (D3-branes)

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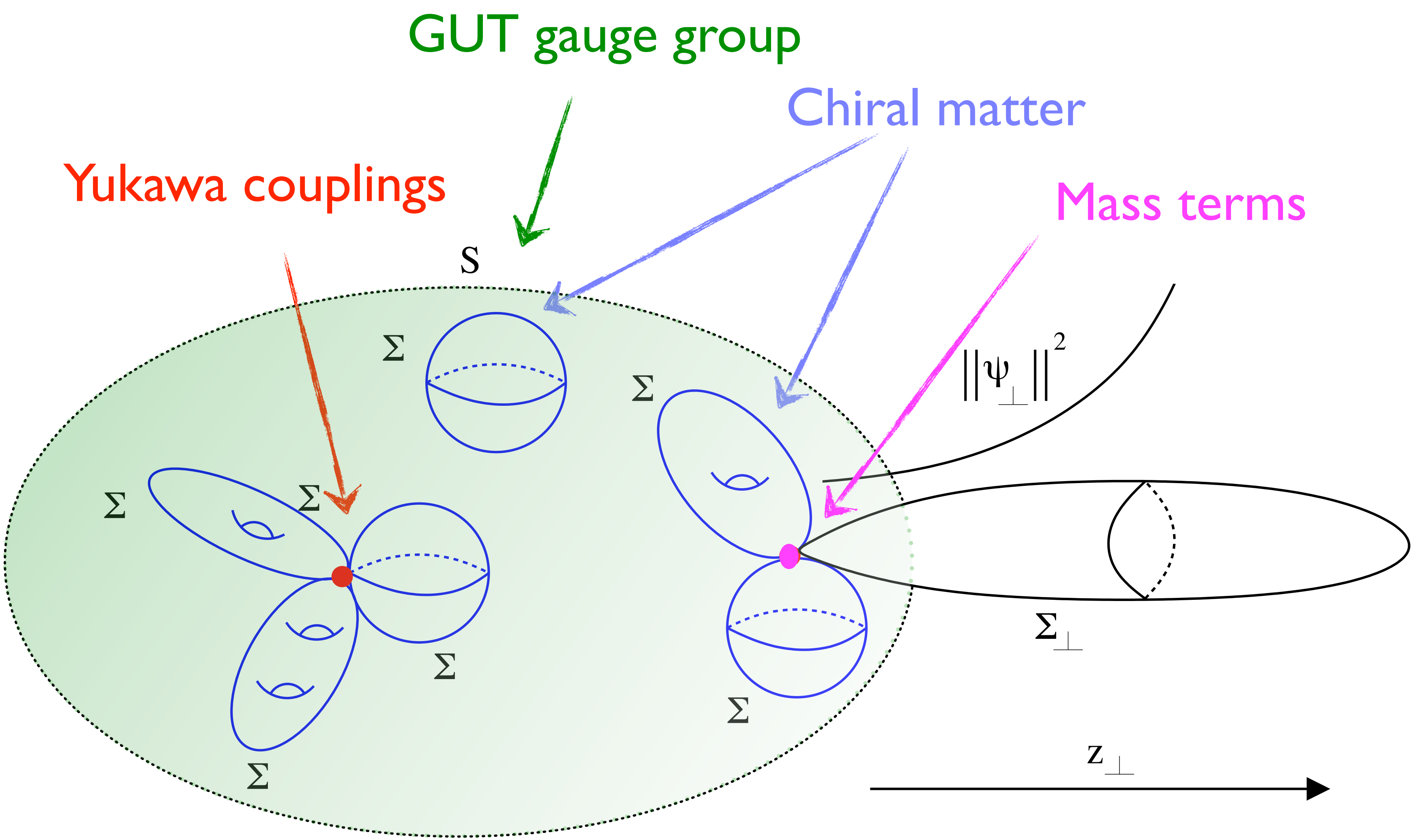

Motivation: GUT's from F-theory

- F-theory GUT local models have recently attracted a lot of attention, and shown to contain a number of phenomenological virtues
- In particular considerable effort has been devoted to show that in the range $M_{SUSY} << M << M_{GUT}$ one can have

Beasley, Heckman, Vafa '08
Donagi & Wijnholt '08

SM gauge group

MSSM matter content

No exotic matter

Acceptable Yukawas and μ-term

Acceptable proton lifetime → R-parity
→ No 5D & 6D operators (No Higgs triplets)

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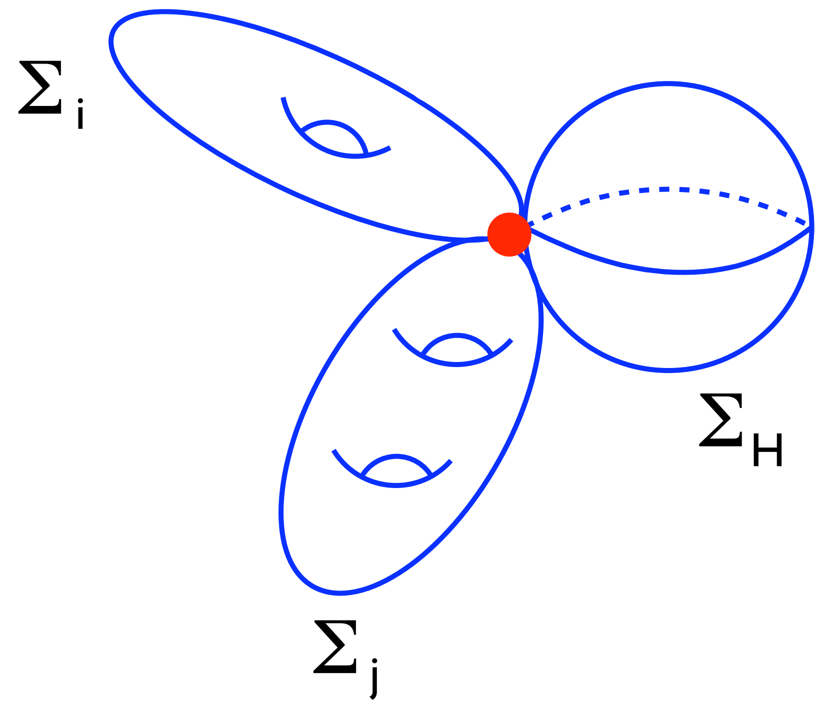
F-theory Yukawas

- In this framework, MSSM matter localizes on complex curves on S
- Yukawas couplings then arise from the triple intersection of these curves



SU(5):

$$5_H \times 10_M \times 10_M$$
$$\bar{5}_H \times \bar{5}_M \times 10_M$$

$F_{U(1)Y}$

SU(3)xSU(2)xU(1)Y: $W_{MSSM} = \lambda_u^{ij} Q^i U^j H_u + \lambda_d^{ij} Q^i D^j H_d + \lambda_l^{ij} L^i E^j H_d$

F-theory Yukawas

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- The holomorphic piece of the Yukawas can be extracted from integrating the 8d Chern-Simons action

Beasley, Heckman, Vafa '08

(2,0)-form

$$W = \int_S \mathrm{Tr}(F_S^{(0,2)} \wedge \Phi) = \int_S \mathrm{Tr}(\bar{\partial} A \wedge \Phi) + \int_S \mathrm{Tr}(A \wedge A \wedge \Phi)$$

$$\begin{aligned} A_{\bar{m}} &= a_{\bar{m}} + \theta \psi_{\bar{m}} \\ \Phi_{12} &= \varphi_{12} + \theta \chi_{12} \end{aligned}$$

$$Y_{ij} = \int_S d\mu\, \psi_{\bar{1}}^i \psi_{\bar{2}}^j \varphi_{12}$$

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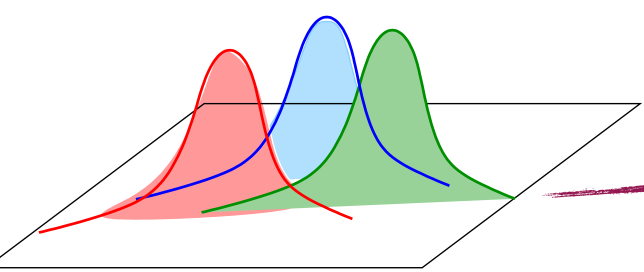

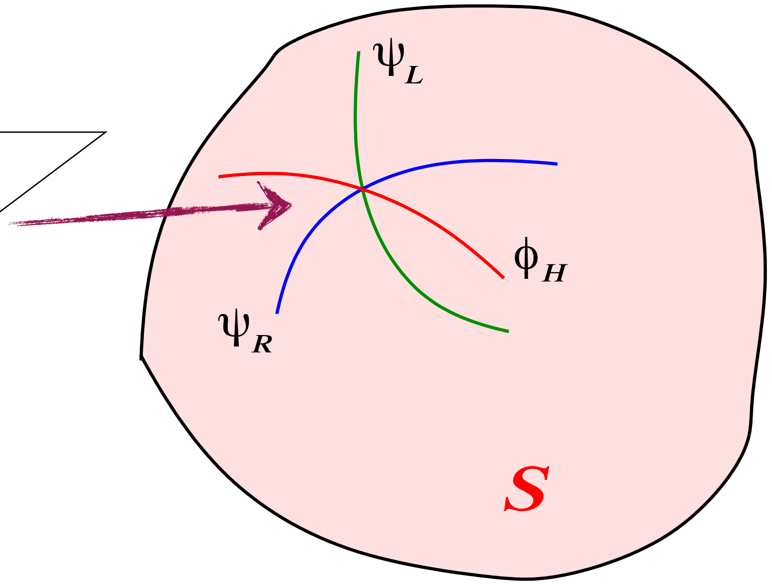

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F-theory Yukawas

- In this framework, MSSM matter localizes on complex curves on S
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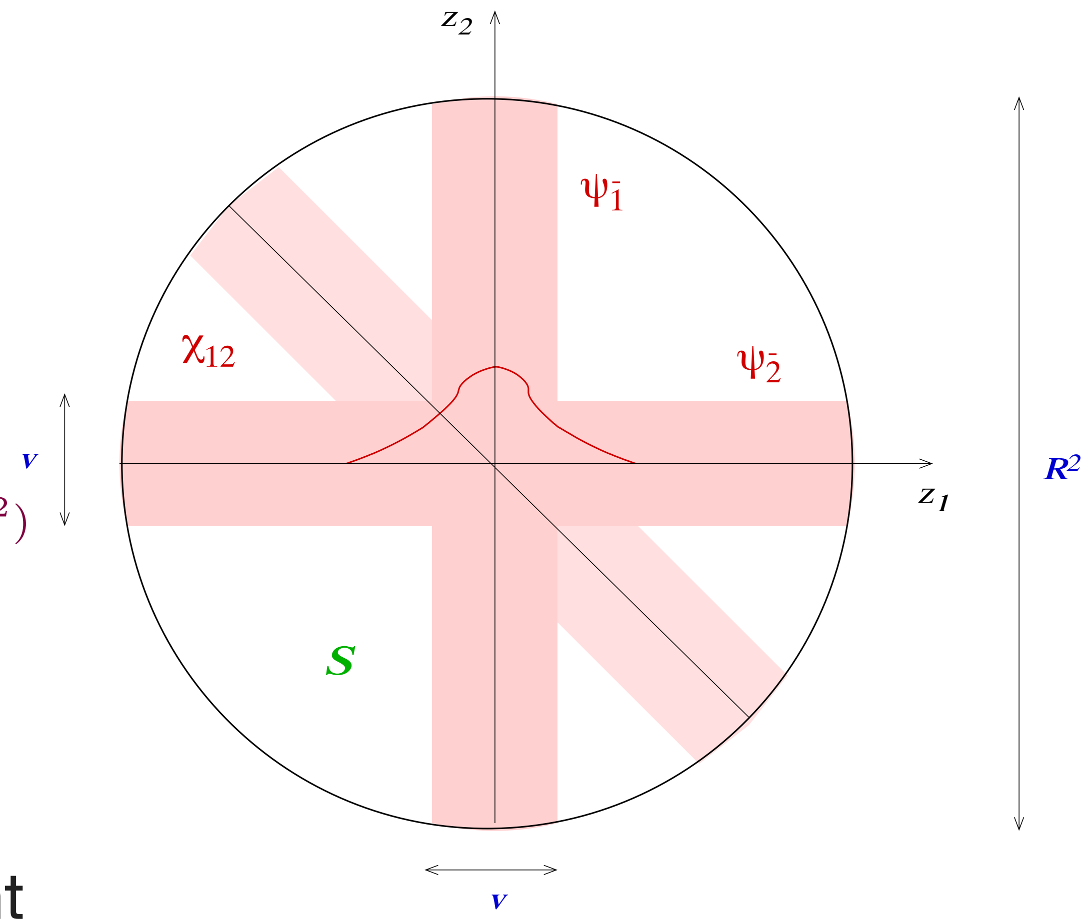
$$Y_{ij} = \int_S d\mu\, \psi_{\bar{1}}^{i} \psi_{\bar{2}}^{j} \varphi_{12}$$

$$d\mu = d^2 z_1 d^2 z_2\, e^{-m^2(|z_1|^2+|z_2|^2+\frac{1}{\sqrt{2}}|z_1+z_2|^2)}$$



U(1) symmetry: $z_i \rightarrow e^{i\alpha} z_i$

so only those integrands invariant under this symmetry will survive...

Heckman & Vafa '08
Font & Ibáñez '09

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$$Y_{ij} = \int_S d\mu\, \psi_1^i \psi_2^j \varphi_{12}$$

- Solving the eom for the matter fields we have

$$\psi_1^i \psi_2^j \varphi_{12} = f_i(z_2) g_j(z_1) G(z_1, \bar{z}_1, z_2, \bar{z}_2)$$

$$f_i = z_2^{3-i}$$
$$g_j = z_1^{3-j}$$

For constant fluxes G only depends on $|z_1|^2$ and $|z_1|^2$, so only $Y_{33} \neq 0$

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For general G one expects an expansion around the triple intersection, with terms of the form $(z_1\bar{z}_1)^a (z_2\bar{z}_2)^b (\bar{z}_1)^{3-j} (\bar{z}_1)^{3-i}$ that contribute to the other Yukawas

However all such latter contributions cancel out $\Longrightarrow$ Rank one Yukawa problem

Cecotti, Cheng, Heckman, Vafa '09

F-theory Recap

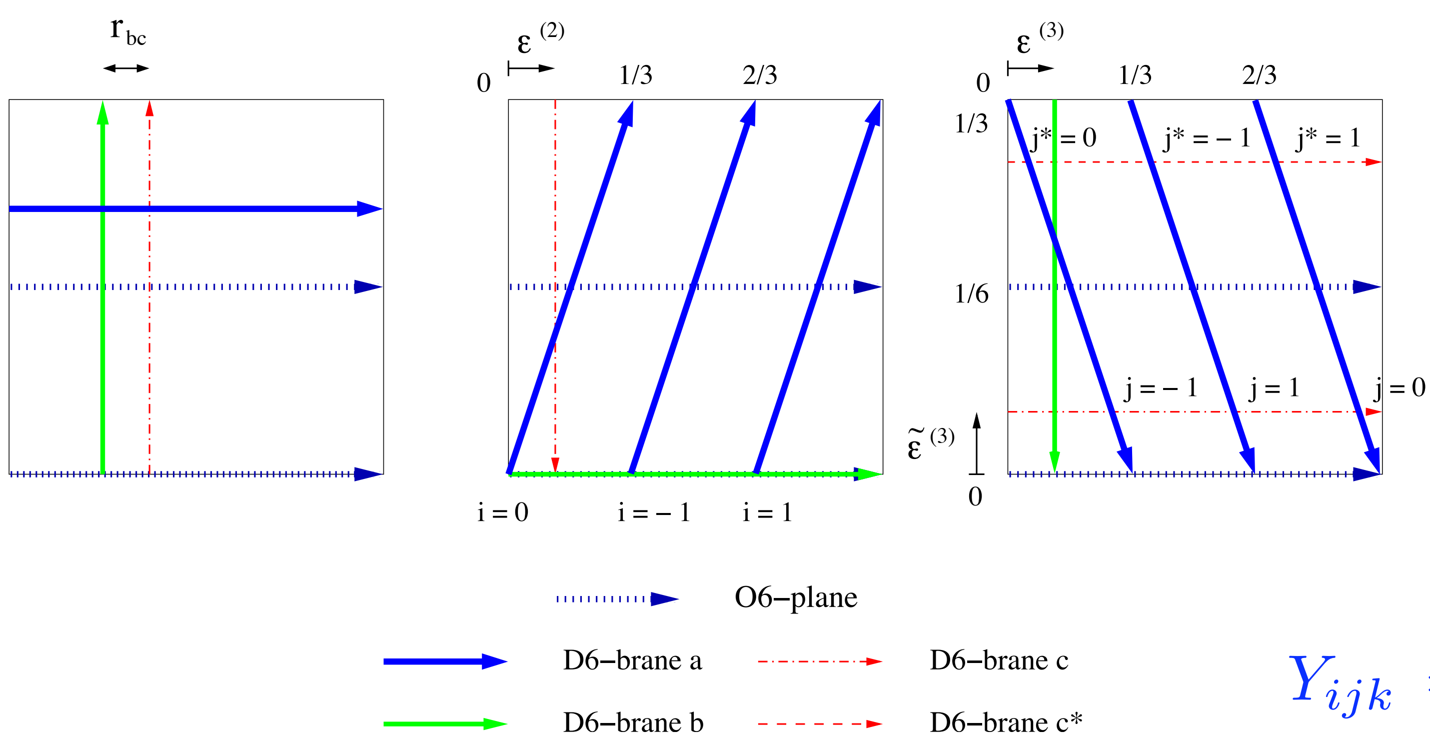
- The above setup provides an interesting framework to reproduce the flavor hierarchies present in the Standard Model
- One however needs a mechanism that modifies the above rank one Yukawa matrix by a small amount
- By the results of Cecotti et al.[0910.0477], such contribution does not arise from the seven-brane theory itself
  $\Rightarrow$ one must consider external effects that modify the superpotential
- It was proposed in Cecotti et al.[0910.0477] that
  - Such effects could be bulk fluxes $G_3 = F_3 - \tau H_3$
  - Their contribution is encoded in a non-commutative deformation
- In the following, we will argue that such effects can only be of non-perturbative origin

Rank one Yukawas from intersecting branes

- Models with rank one Yukawas can also be obtained in the context of intersecting D6-branes on toroidal orbifolds

Cremades, Ibáñez, F.M. '03

	N_α	(n_α^1, m_α^1)	(n_α^2, m_α^2)	(n_α^3, m_α^3)
U(3)xU(1)	$N_a = 3+1$	$(1,0)$	$(1,3)$	$(1,-3)$
USp(2)	$N_b = 1$	$(0,1)$	$(1,0)$	$(0,-1)$
USp(2)	$N_c = 1$	$(0,1)$	$(0,-1)$	$(1,0)$



$$Y_{ijk} = e^{-A_{ijk}}$$

Rank one Yukawas from intersecting branes

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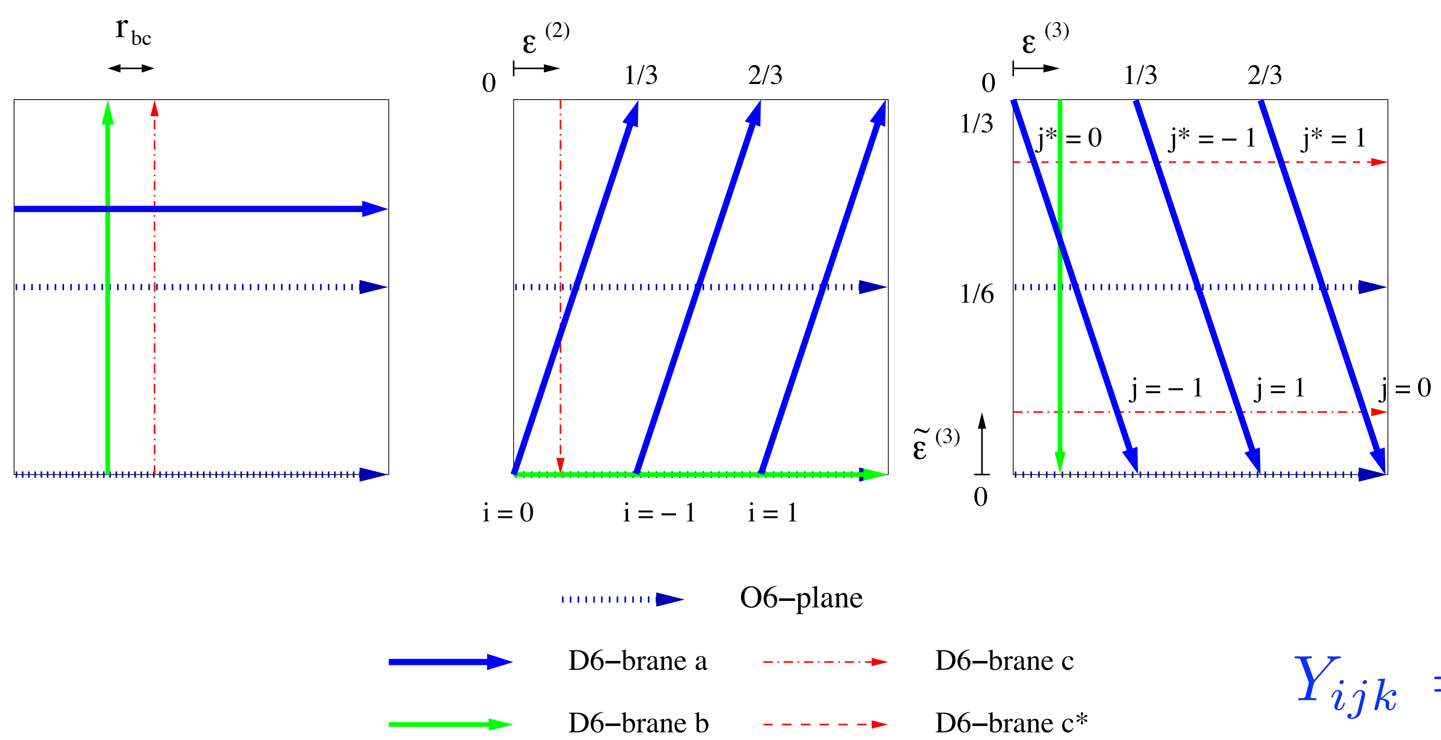
$$Y^U \sim A \cdot \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \cdot B, \qquad Y^D \sim A \cdot \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \cdot \tilde{B}.$$



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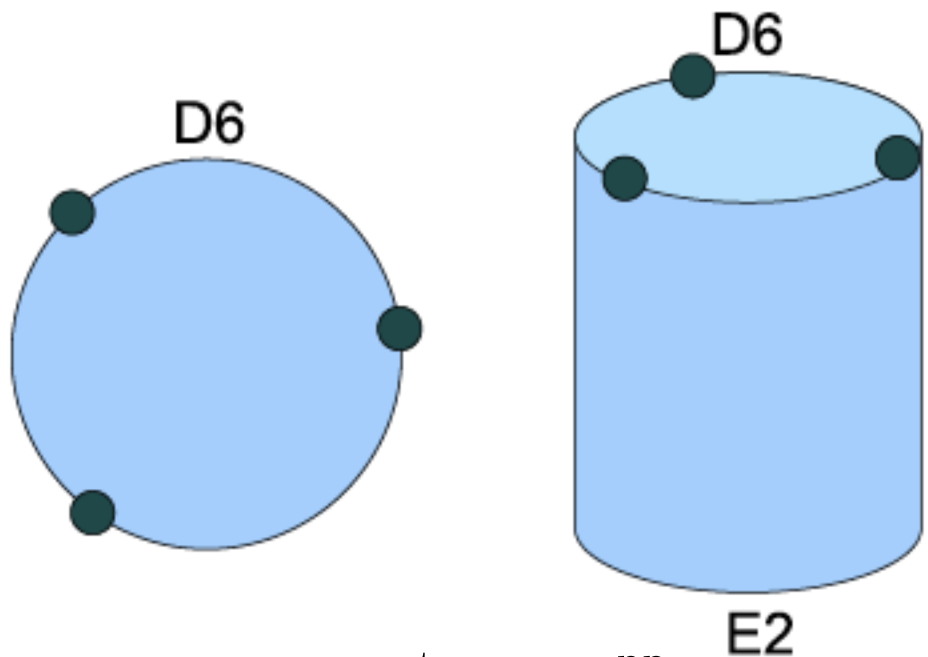
Rank one Yukawas from intersecting branes

- It was then proposed that this rank one problem could be solved by the one loop contribution of E2-instantons

Abel & Goodsell '06



$$Y_{ij} = Y_{ij}^{\text{tree}} + Y_{ij}^{\text{np}}$$

Conditions:
E2 rigid, O(1), and
does not intersect the
MSSM D6-branes

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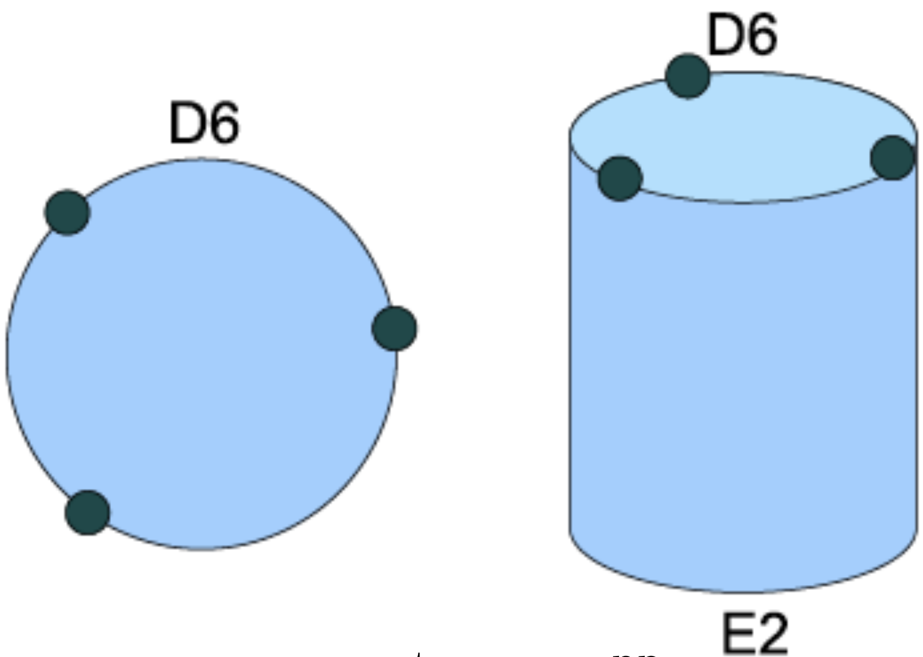

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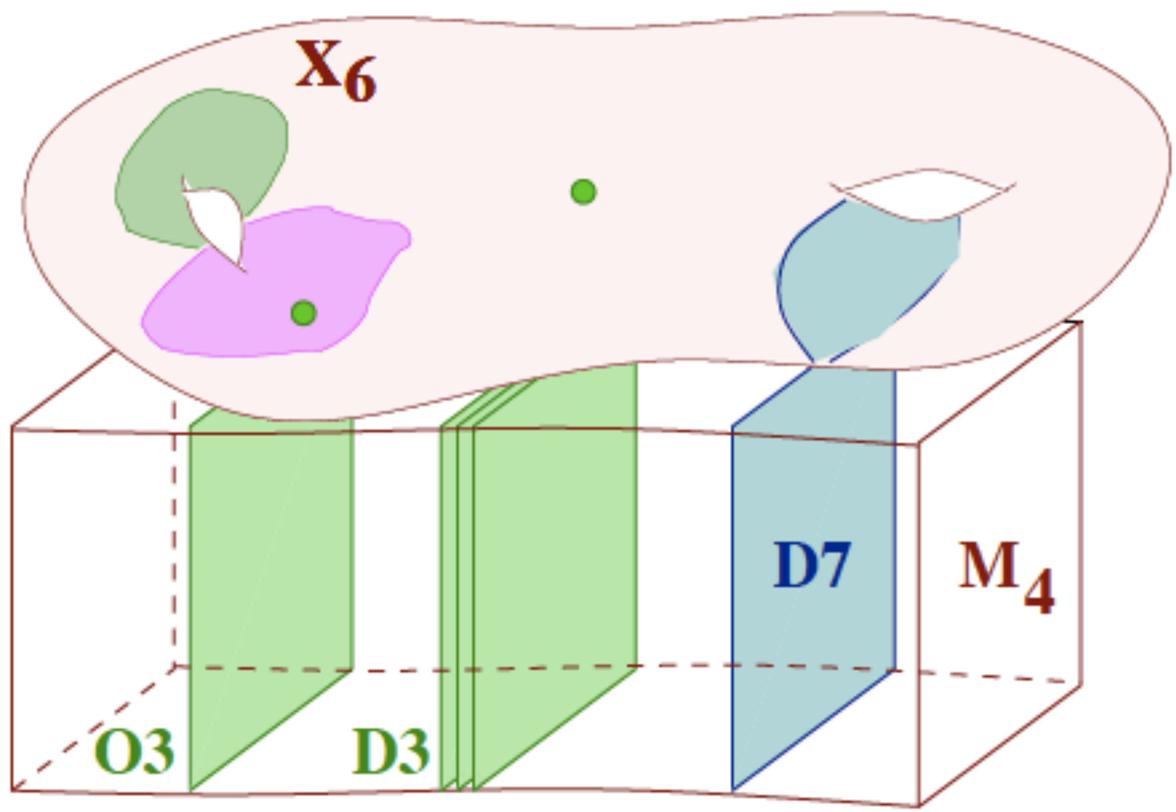
Question: Can we apply this idea to F-theory? How does $W^{\rm np}$ look like?

W^{np} via backreaction

- Let us consider type IIB string theory compactified on a warped Calabi-Yau with ISD fluxes

Gidings, Kachru, Polchinski'01



W^{np} via backreaction

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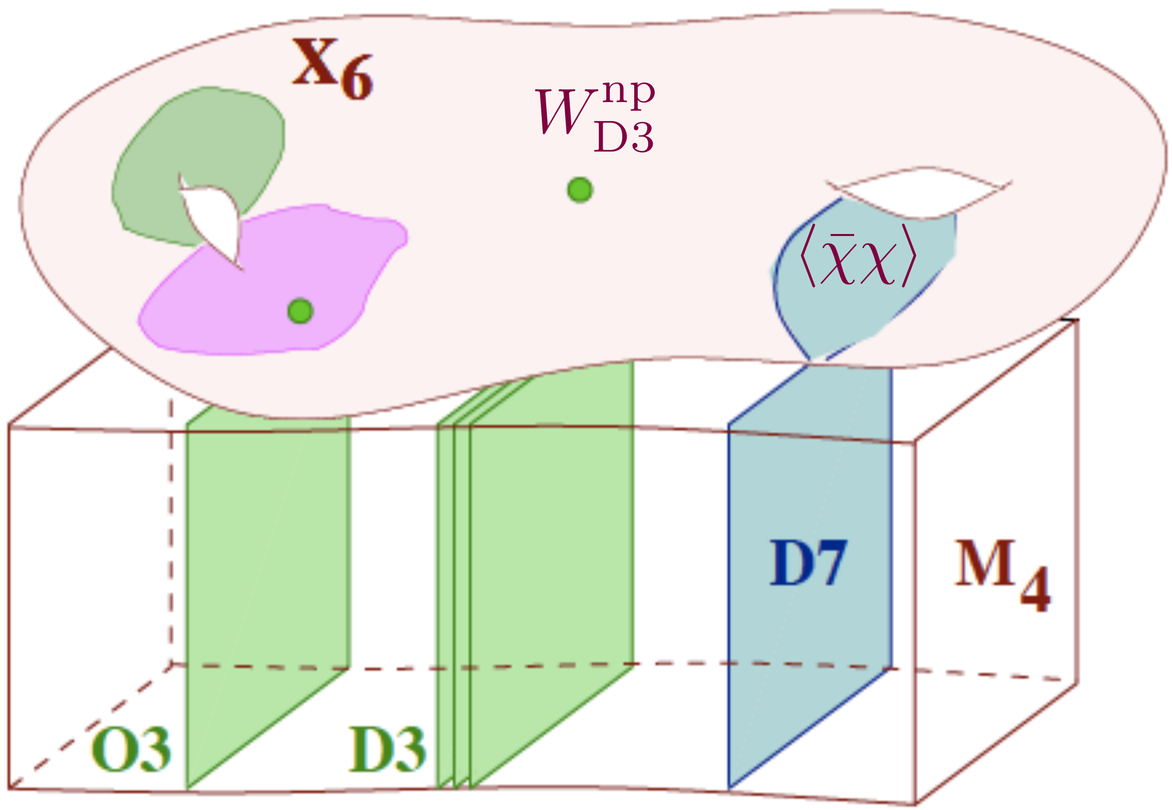
- If a D7-brane develops a gaugino condensate, a non-perturbative superpotential will be generated for the D3-brane position fields, such that it vanishes on top of the D7 4-cycle

  Ganor '96



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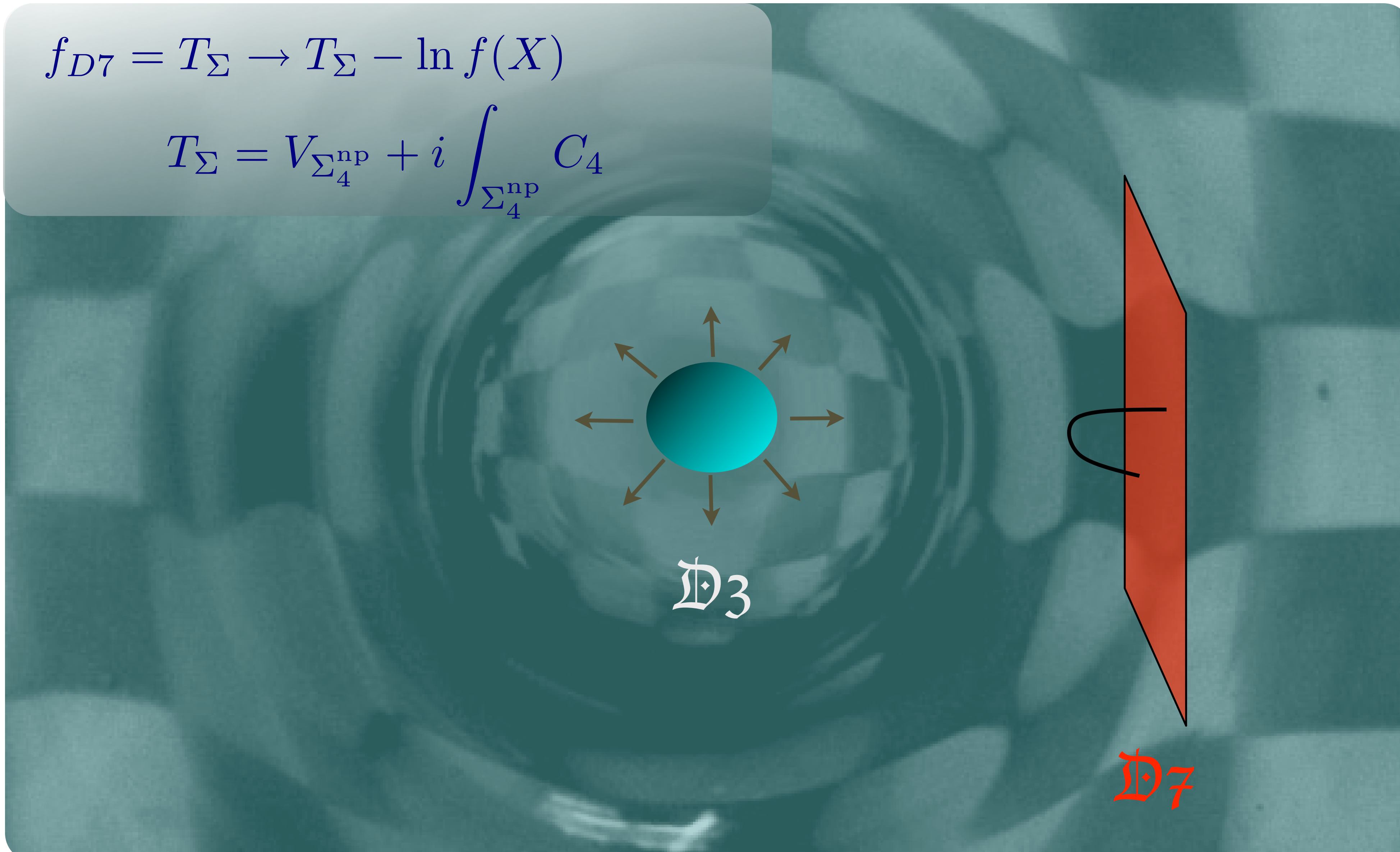
- We can compute such superpotential
  - In the one-loop open string channel *Berg, Haack, Körs '04*
  - In the tree-level closed string channel *Baumann et al. '06*

W^{np} via backreaction

- In the latter case, one basically computes how, via its backreaction, the D3-brane position modifies the D7 gauge kinetic function

$$f_{D7} = T_\Sigma \to T_\Sigma - \ln f(X)$$

$$T_\Sigma = V_{\Sigma_4^{\rm np}} + i \int_{\Sigma_4^{\rm np}} C_4$$



$W^{\rm np}$ via backreaction

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- The result is

$$W^{\rm np} = M^3 e^{-f_{D7}/n} = \mathcal{A}\, e^{-T_\Sigma/n} f(z_{\rm D3})^{1/n} \qquad n = \#{\rm D7'}{\rm s}$$

W^{np} via backreaction

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- The result is

$$W_{\mathrm{D3}}^{\mathrm{np}} = M^3 e^{-f_{D7}/n} = \mathcal{A}\, e^{-[T_\Sigma - \mathrm{Tr}\ln f(Z_{\mathrm{D3}})]/n} \qquad n = \#\mathrm{D7}'\mathrm{s}$$

$$= \mathcal{A}\, e^{-T_\Sigma/n}[\det f(Z_{\mathrm{D3}})]^{1/n}$$

W^{np} for D7-branes

- Let us now replace the D3-brane by a D7-brane wrapping a 4-cycle S_4
- If this D7-brane is magnetized ($F \neq 0$) it will carry an induced D3-brane charge and tension, given by $N_{\rm D3} = \frac{1}{8\pi^2}\int_{\mathcal{S}_4} {\rm Tr}(F\wedge F)$
- Hence, it will also backreact on the warping and the RR field C_4.
  $\Rightarrow$ The position moduli of S_4 should also couple to T_Σ
- In fact, if S_4 and Σ_4^{np} do not intersect, we can treat the D7 as N_{D3} smeared out D3-branes over S_4, with density $\rho = {\rm Tr}\, F^2/8\pi^2$
- We then obtain

$$W^{\rm np}_{\rm D7} \quad = \quad \mathcal{A}\, e^{-T_\Sigma} \exp\left[\frac{1}{8\pi^2}\int_{\mathcal{S}_4} {\rm STr}(\ln f\, F\wedge F)\right]$$

W$^{\mathrm{np}}$ for D7-branes

- To extract the field dependence of this superpotential we must perform a non-Abelian Taylor expansion on the position field $\phi = 2\pi\alpha' w$

$$W^{\mathrm{np}}_{\mathrm{D7}} \quad = \quad \mathcal{A}\, e^{-T_\Sigma} \exp\left[\frac{1}{8\pi^2}\int_{\mathcal{S}_4} \mathrm{STr}(\ln f\, F \wedge F)\right]$$

$$\downarrow$$

$$W^{\mathrm{np}}_{\mathrm{D7}} = \underbrace{\mathcal{A} e^{-T_\Sigma} f|^{N_{\mathrm{D3}}}_{\mathcal{S}_4}}_{\text{const.}} + \frac{1}{8\pi^2}\int_{\mathcal{S}_4} \theta\, \mathrm{Str}(\phi\, F \wedge F) + \ldots$$

$$\theta := 2\pi\alpha' \mathcal{A} e^{-T_\Sigma} (f^{N_{\mathrm{D3}}} \partial_w \log f)|_{\mathcal{S}_4}$$

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W^{np} for D7-branes

- We can perform the same expansion for the D7-brane tree-level superpotential

$$W_{\rm D7}^{\rm tree} = \int_{\Gamma_5} {\rm Str}\,\Omega \wedge F$$

Martucci '06

- We obtain the full superpotential

$$W_{\rm D7} = \int_{\mathcal{S}_4} \left[(\iota_w \Omega) \wedge {\rm tr}(\phi\, F) + \frac{1}{2}\,\theta\, {\rm Str}(\phi\, F^2) + \ldots \right]$$

$$\int_{\mathcal{S}_4} {\rm Tr}(F_S^{(0,2)} \wedge \Phi)$$

dim. 5 correction

Comments

- We have treated a magnetized D7-brane as a bunch of smeared out D3-branes but, actually, its backreaction is more involved
- Indeed, D7-branes also source the axio-dilaton τ. It is easy to see, however, that the action of a O(1) E3-instanton is independent of τ $\Rightarrow$ No further contributions to W^{np}
- We have found that the non-perturbative correction is given by a higher dim. operator. The contribution to the Yukawas can be extracted from terms involving only three fluctuations

$$\int_{\mathcal{S}_4} \theta\, \epsilon^{i\bar{j}k\bar{l}} \mathrm{Str}\left(\phi\, D_i A_{\bar{j}} D_k A_{\bar{l}}\right)$$

$$D_k = \alpha'^{1/2}(\partial_k + i\langle A_k \rangle \wedge)$$ (Froggat-Nielsen mech.)

... as well as from the modified eom

W^{np} Recap

- F-theory models can reproduce a flavor hierarchy, but without any external effect they suffer from a rank one Yukawa problem
- We have shown that such effect can be generated by non-perturbative dynamics, which correct the seven-brane tree-level superpotential
- Such correction exists if the seven-brane carries D3-brane charge. The corrections to W_{D3} and W_{D7} are closely related
- Here the corrected Yukawas are not perturbatively forbidden by anomalous global U(1) symmetries. The non-perturbative corrections are however relevant in the sense that they lift degeneracies.
- While we have worked in the type IIB limit, our results extend trivially to F-theory
- The non-perturbative correction to the Yukawas can be understood in terms of a dim. 5 operator multiplied by a function θ

W^{np} as a β-deformation

- This D7-brane superpotential

$$W_{\rm D7} = \int_{\mathcal{S}_4} \left[(\iota_w \Omega) \wedge \mathrm{tr}(\phi\, F) + \frac{1}{2}\, \theta\, \mathrm{Str}(\phi\, F^2) + \ldots \right]$$

can also be generated in certain exotic type IIB vacua known as β-deformed backgrounds *Gualtieri '04*

- These are naturally described in the language of generalized complex geometry, that encodes the Killing spinor of the background in terms of polyforms

$$\epsilon = \begin{pmatrix} \epsilon_1 \\ \epsilon_2 \end{pmatrix} \qquad \epsilon_i = \zeta_i \otimes \eta_i + \zeta_i^* \otimes \eta_i^*$$

$$\{\eta_1, \eta_2\} \quad \leftrightarrow \quad \{\Psi_1, \Psi_2\} \qquad \left\{ \begin{array}{lcl} \Psi_1 & = & \psi_0 + \psi_2 + \psi_4 + \psi_6 \\ \Psi_2 & = & \psi_1 + \psi_3 + \psi_5 \end{array} \right.$$

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Gualtieri '04

- These are naturally described in the language of generalized complex geometry, that encodes the Killing spinor of the background in terms of polyforms
  - For a warped Kähler manifold $\Psi_2 = \Omega_3$
  - For a β-deformed background $\Psi_2 = \psi_1 + \Omega_3$ $\qquad \psi_k = \beta^{ij}\Omega_{ijk}$

- Then:

$$\begin{aligned} W_{\rm D3} &= \chi_0 \\ W_{\rm D7} &= \int_{\mathcal{S}_4} (\pi\alpha'\chi_0 F \wedge F + \chi_2 \wedge F) \end{aligned}$$

Martucci '06

$$\begin{aligned} d\chi_2 &= \Omega \\ d\chi_0 &= \psi_1 \end{aligned}$$

W^{np} as a β-deformation

- It has been argued that the effect of a β-deformation on a D-brane worldvolume can be seen as a non-commutative deformation of the gauge theory

Kapustin'03
Pestun'06

- This suggests the identification

$$\text{np correction} \Leftrightarrow \text{nc deformation}$$

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- Indeed, in the β-deformed superpotential the F-flatness condition reads

$$(\iota_X \psi_1)|_{\mathcal{S}_4} F^2 + 2(\iota_X \Omega)|_{\mathcal{S}_4} \wedge F = 0 \qquad \forall X \in TM|_{\mathcal{S}_4}$$

and so $F^{(0,2)} \neq 0$. It can however be expressed as the condition

$$\hat{F}^{(0,2)} = 0$$

with $\hat{F}$ constructed via the Seiberg-Witten map

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- In fact, one can map the nc superpotential

$$\hat{W}_{\mathrm{D7}} = \int_{\mathcal{S}_4} \mathrm{tr}(\hat{\varphi} \circledast \hat{F})$$

SW map

$$\begin{aligned} \hat{F}_{\alpha\beta} &= F_{\alpha\beta} + \frac{1}{2}\Theta^{\gamma\delta}(F_{\alpha\gamma}F_{\delta\beta} + F_{\delta\beta}F_{\alpha\gamma}) \\ &\quad + \frac{1}{4}\Theta^{\gamma\delta}[A_\gamma(D_\delta F_{\alpha\beta} + \partial_\delta F_{\alpha\beta}) \\ &\quad + (D_\delta F_{\alpha\beta} + \partial_\delta F_{\alpha\beta})A_\gamma] + \mathcal{O}(\theta^2) \\ \hat{\phi} &= \phi + \frac{1}{4}\Theta^{\alpha\beta}[A_\alpha(\partial_\beta\phi + D_\beta\phi) \\ &\quad + (\partial_\beta\phi + D_\beta\phi)A_\alpha] + \mathcal{O}(\theta^2) \end{aligned}$$

$$\Downarrow$$

$$W_{\mathrm{D7}} = \int_{\mathcal{S}_4} \left[(\iota_w\Omega)\wedge \mathrm{tr}(\phi\, F) + \frac{1}{2}\,\theta\, \mathrm{Str}(\phi\, F^2) + \ldots\right]$$

Conclusions

- Motivated by F-theory, we have shown that non-perturbative effects correct non-trivially the tree-level superpotential of seven-branes
- We have provided an explicit and simple expression for this correction, which allows to compute its effects even at a local level
- The correction can either be expressed in terms of a dim. 5 operator or as a non-commutative deformation, via the SW map

Conclusions

- Motivated by F-theory, we have shown that non-perturbative effects correct non-trivially the tree-level superpotential of seven-branes
- We have provided an explicit and simple expression for this correction, which allows to compute its effects even at a local level
- The correction can either be expressed in terms of a dim. 5 operator or as a non-commutative deformation, via the SW map
- It was argued by Cecotti et al.[0910.0477] that such nc deformed superpotential generically solve the rank one Yukawa problem. There, however, the origin of the nc deformation was advocated to bg fluxes
- Reversing our above discussion, one can see that the nc deformation for D7-branes has the same origin that a superpotential for D3-branes
- However, the no-scale condition for these wCY backgrounds implies that $W_{D3} = 0$ at tree-level ⇒ nc deformation must have a np origin!!