Yukawa couplings at the point of E_8 in F-theory

Gianluca Zoccarato

Instituto de Fisica Teorica, UAM/CSIC

String Phenomenology 2014, ICTP Trieste, July 8th 2014

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Instituto de Física Teórica UAM-CSIC

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Marchesano, Regalado, GZ: work in progress

Font, Ibañez, Marchesano, Regalado '12

Font, Marchesano, Regalado, GZ '13

F-theory GUTs

- Gauge degrees of freedom are localized on 7-branes
- F-theory offers something more than type IIB
    - Non-perturbative in the string coupling g_s
    - Mutually non-local branes can be present

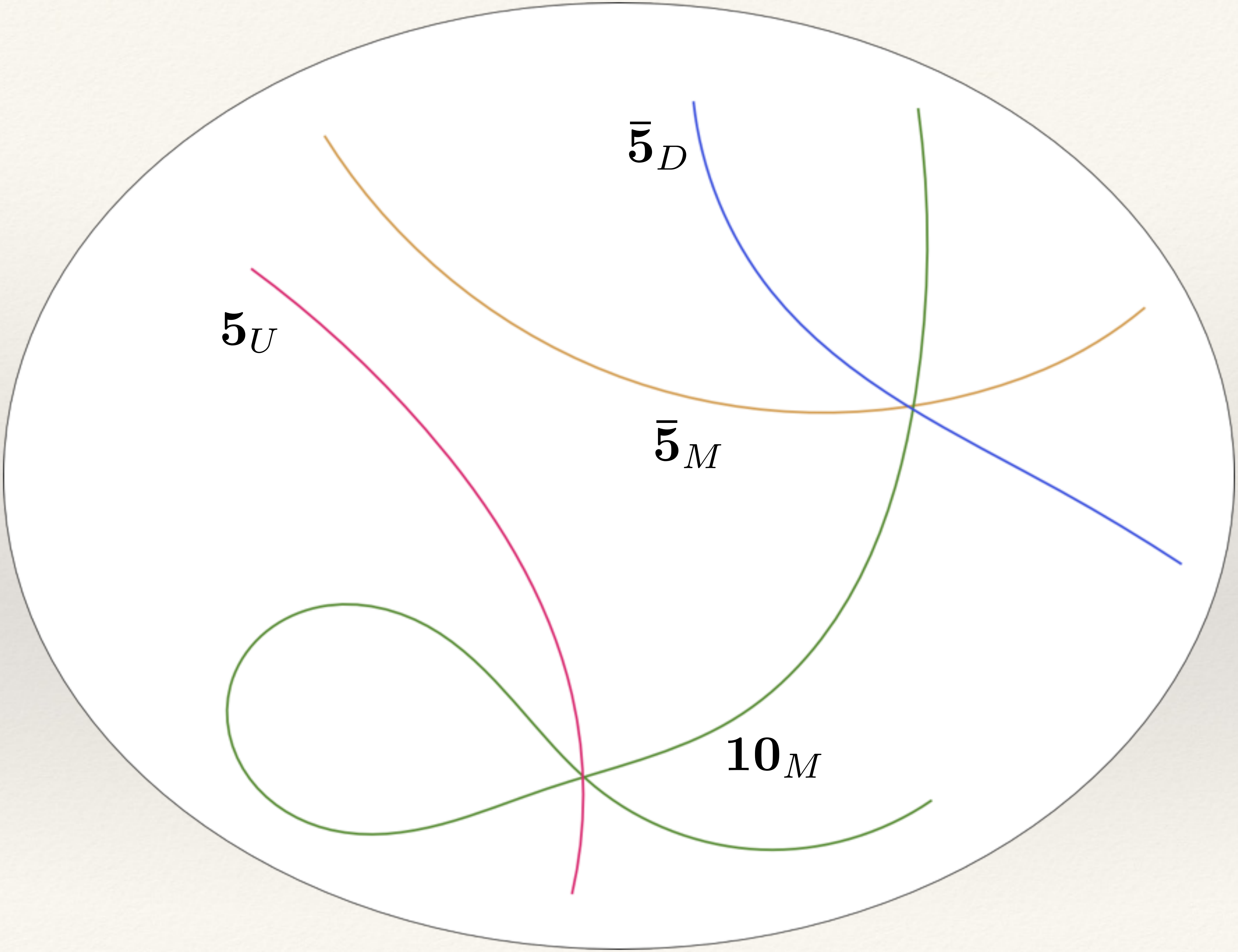
↓

Exceptional groups are possible

7-brane field theory

Beasley, Heckman, Vafa '08

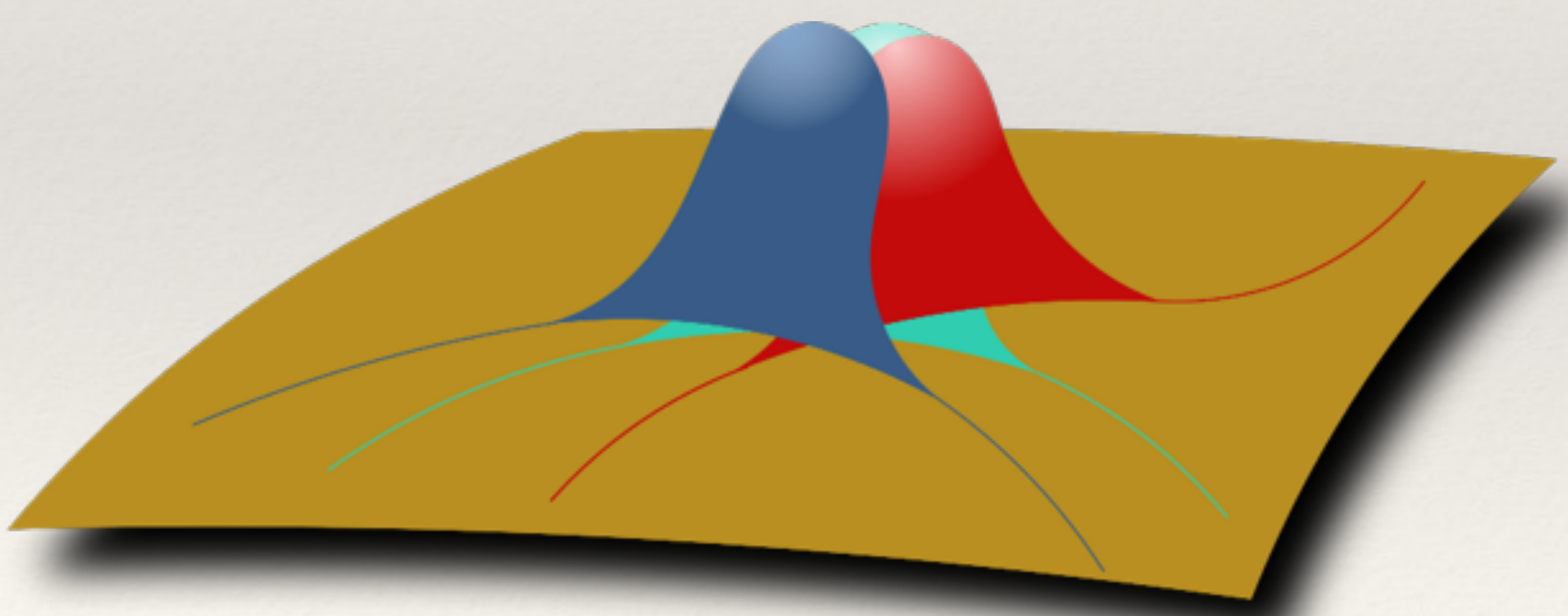
- Local approach: SU(5) gauge theory on $\mathbb{R}^4 \times S_{GUT}$
- Matter fields localize on complex curves
- Yukawa couplings arise at triple intersections


$\bar{\mathbf{5}}_D$
$\mathbf{5}_U$
$\bar{\mathbf{5}}_M$
$\mathbf{10}_M$

Holomorphic couplings

- Holomorphic superpotential can be computed via dimensional reduction

$$W = \int_S F^{(0,2)} \wedge \Phi = \int_S \bar{\partial} A \wedge \Phi + \boxed{\int_S A \wedge A \wedge \Phi}$$



$$W = y^{ijk} a_i a_j \phi_k$$

$$y^{ijk} = \int_S \psi_a^i \psi_a^j \phi^k$$

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$$W = \int_S F^{(0,2)} \wedge \Phi = \int_S \bar{\partial} A \wedge \Phi + \boxed{\int_S A \wedge A \wedge \Phi}$$

$$\downarrow$$

$$W = y^{ijk} a_i a_j \phi_k$$

$$y^{ijk} = \int_S \psi_a^i \psi_a^j \phi^k$$

- Couplings independent of fluxes
- Can be computed via residue formula

Cecotti, Cheng, Heckman, Vafa '09

Real Couplings

- Real couplings are obtained asking for normalized wavefunctions

$$\int_S \psi_i \bar{\psi}_{\bar{\jmath}} = \delta_{i\bar{\jmath}}$$

- Introduces flux dependence in the fluxes
  - GUT group breaking via hypercharge flux gives deviations from minimal GUT predictions for Yukawa couplings

$$Y_D \neq Y_L$$

Non-perturbative effects

- However the Yukawa matrix has rank 1
- Non-perturbative physics induces corrections to the superpotential

Marchesano, Martucci '09

$$W = \int_S F^{(0,2)} \wedge \Phi + \frac{\epsilon}{2} \sum_{n \in \mathbb{N}} \int_S \theta_n \mathrm{STr} \left(\Phi^n F \wedge F \right)$$

Couplings in SU(5) GUT

- In SU(5) GUT we need the following Yukawa couplings

$$W = \lambda_{ij}^{(u)} \mathbf{10}^i \mathbf{10}^j \mathbf{5}_U + \lambda_{ij}^{(d)} \mathbf{10}^i \bar{\mathbf{5}}^j \bar{\mathbf{5}}_D$$

Up Yukawa

- Masses for the up quarks
- Needs E_6 enhancement (not allowed in IIB)
- Needs T-brane background

Down Yukawa

- Masses for the down quarks and leptons
- Needs SO(12) enhancement
- Can be described by intersecting branes

Intersecting branes

$$[\Phi, \overline{\Phi}] = 0$$

- Only primitive fluxes

$$\omega \wedge F = 0$$

T-branes

Cecotti, Cordova, Heckman, Vafa '10

$$[\Phi, \overline{\Phi}] \neq 0$$

- Requires non-primitive fluxes

$$\omega \wedge F + \frac{1}{2}[\Phi, \overline{\Phi}] = 0$$

Couplings in SU(5) GUT

- The couplings are generated at different points

Difficult to study flavour structure

↓

Combine the two points in a single one → E_7

→ E_8

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Heckman, Tavanfar, Vafa '09

E_8 Yukawas

- We choose a background that breaks E_8 as follows

$$E_8 \to SU(5)_{GUT} \times SU(5)_\perp$$

$$\Phi \sim \begin{pmatrix} \lambda_1 & 1 & 0 & 0 & 0 \\ x & \lambda_1 & 0 & 0 & 0 \\ 0 & 0 & -2\lambda_1 - \lambda_2 & 1 & 0 \\ 0 & 0 & y & -2\lambda_1 - \lambda_2 & 0 \\ 0 & 0 & 0 & 0 & 2(\lambda_1 + \lambda_2) \end{pmatrix}$$

$\mathbb{Z}_2 \times \mathbb{Z}_2$ monodromy

E_8 Yukawas

- We choose a background that breaks E_8 as follows

$$E_8 \to SU(5)_{GUT} \times SU(5)_\perp$$

- We add fluxes

    - Get chiral matter in 4d
    - Achieve GUT group breaking (hypercharge flux)

Donagi, Wijnholt '08

$$SU(5) \to SU(3) \times SU(2) \times U(1)_Y$$

Up Yukawa Matrix

$$\lambda_{ij}^{(u)} \sim \begin{pmatrix} 0 & 0 & \mathcal{O}(\epsilon) \\ 0 & \mathcal{O}(\epsilon) & 0 \\ \mathcal{O}(\epsilon) & 0 & 1 \end{pmatrix} + \mathcal{O}(\epsilon^2)$$

Down Yukawa Matrix

$$\lambda_{ij}^{(d)} \sim \begin{pmatrix} 0 & 0 & \mathcal{O}(\epsilon) \\ 0 & \mathcal{O}(\epsilon) & \mathcal{O}(\epsilon) \\ \mathcal{O}(\epsilon) & \mathcal{O}(\epsilon) & 1 \end{pmatrix} + \mathcal{O}(\epsilon^2)$$

Singlets

- From the adjoint of E_8 we get singlets

$$\mathbf{adj}_{E_8} \to \mathbf{adj}_{SU(5)} + \mathbf{adj}_{SU(5)_\perp} + \ldots$$

Can be used as right handed neutrinos, to generate an effective μ-term, to mediate SUSY breaking

Bouchard, Heckman, Seo, Vafa '09

Heckman, Tavanfar, Vafa '09

Neutrinos and μ-term

- A Dirac mass for neutrinos is present

$$W = \lambda^{(n)} N_R L H_u$$

- Integrating out KK-modes a μ-term is generated

$$W = \frac{1}{\Lambda} S^2 H_u H_d$$

Kim, Nilles '83

Conclusions

- We have studied the flavour structure at E_8 point in F-theory
- Non-perturbative effects increase the rank of the Yukawa matrix and give a hierarchical structure
- Neutrino masses and μ-term are also generated

Thank you