

Yukawa Hierarchies at the point of E_8 in F-theory

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String Phenomenology 2015, IFT Madrid, June 11th 2015



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Based on: [Marchesano, Regalado, G.Z. '15](#)

Related work: [Font, Ibañez, Marchesano, Regalado '12](#)

[Font, Marchesano, Regalado, G.Z. '13](#)

GUTs in F-theory

- Over the last years various aspects of F-theory GUTs have been studied

Gauge coupling unification

MSSM matter content (+ exotics?)

SUSY breaking

U(1) symmetries and proton decay

Discrete symmetries

Realistic Yukawa couplings

Yukawa couplings in SU(5) GUTs

In SU(5) GUTs there are two basic Yukawa couplings

$$Y_{ij} \mathbf{10}_M^i \cdot \mathbf{10}_M^j \cdot \mathbf{5}_U$$

- Mass for up quarks
- Enhancement to E_6

$$Y_{ij} \mathbf{10}_M^i \cdot \bar{\mathbf{5}}_M^j \cdot \bar{\mathbf{5}}_D$$

- Mass for down quarks, leptons
- Enhancement to $SO(12)$

In general the couplings are generated at two different points

$$E_6 + SO(12) \rightarrow \dots$$

Heckman, Tavanfar, Vafa '09

Idea: generate both couplings at a single point

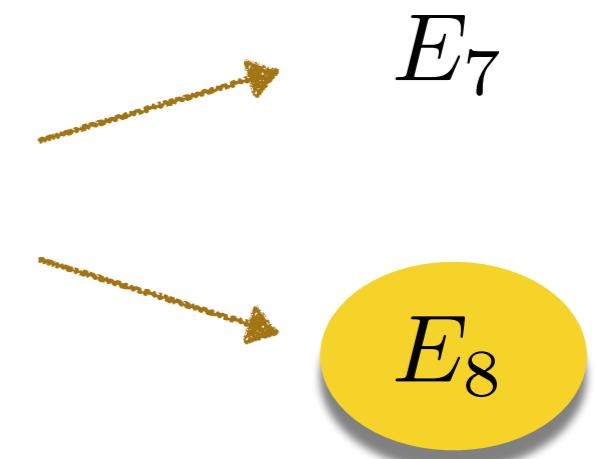
- Possible to compute all couplings using the same local model

I. Compute CKM matrix elements

II. Find preferred value for some MSSM parameters ($\tan \beta$)

- Large separation induces large mixing angles

A group containing both E_6 and $SO(12)$



Local E_8 models

Defining data of the local model

1. Vev of the adjoint Higgs

- Describes the configuration of 7-branes
- Breaks E_8 down to $SU(5)$
- If reconstructible defines the local spectral cover

2. Open string fluxes

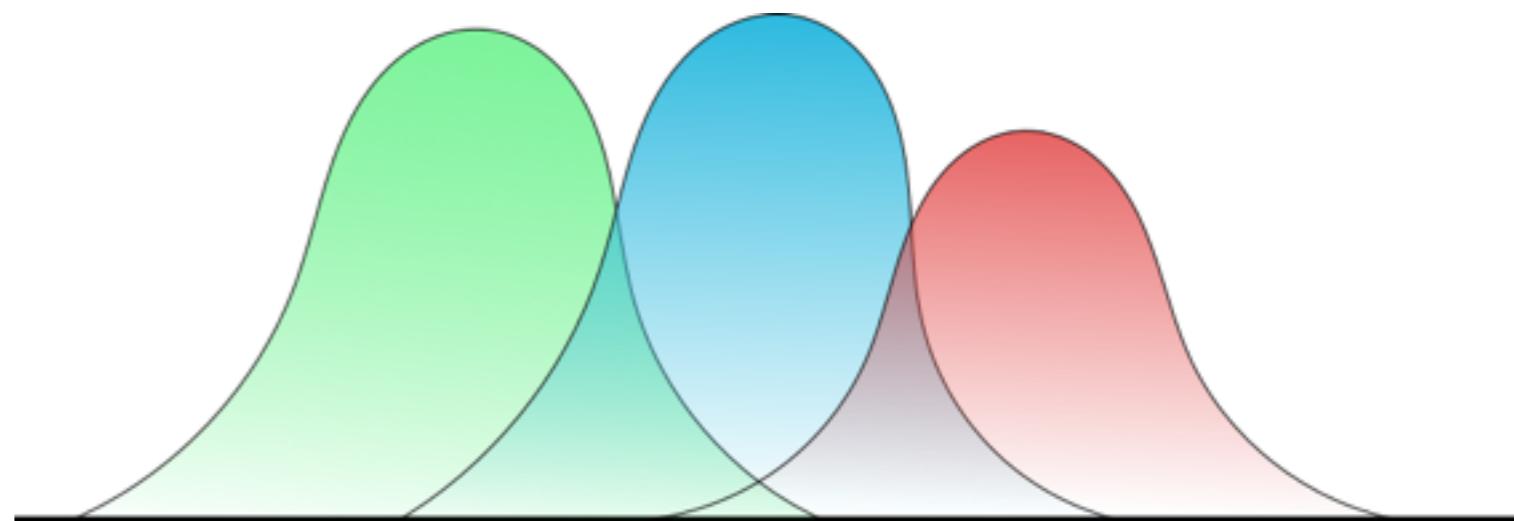
- Generate chirality in 4d
- Break $SU(5)$ down to $SU(3) \times SU(2) \times U(1)_Y$

Yukawa couplings in 8d SYM

Yukawa couplings can be computed by dimensional reduction of the 8d superpotential

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

- Can be computed using a residue formula
- Holomorphic couplings do not depend on flux densities
- Yukawa matrix has rank 1



- Holomorphic couplings do not depend on flux densities



- Physical** couplings depend on flux densities

Canonical kinetic terms for 4d fields $\longrightarrow \int_S \psi_i \bar{\psi}_{\bar{j}} = \delta_{i\bar{j}}$

- Yukawa matrix has rank 1



- Non perturbative corrections deform the superpotential

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

Yukawa matrix has rank 3 and a hierarchy in the eigenvalues

$$(\mathcal{O}(\epsilon^2), \mathcal{O}(\epsilon), \mathcal{O}(1))$$

Catalogue of models

Splitting	Hierarchy	Neutrinos	μ-term
4+4+1	✓	✓	X
3+2 (I)	X		
3+2 (II)	X		
2+2+1 (I)	X		
2+2+1 (II)	X		
2+2+1 (III)	✓	✓	X
2+2+1 (IV)	✓	✓	✓

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2+2+1 (II)	X		
2+2+1 (III)	✓	✓	X
2+2+1 (IV)	✓	✓	✓

Fermion masses at GUT scale

Ross, Serna '07

Possible to accommodate GUT scale masses for $\tan \beta \sim 10 - 20$

$\tan\beta$	10	38	50
m_u/m_c	$2.7 \pm 0.6 \times 10^{-3}$	$2.7 \pm 0.6 \times 10^{-3}$	$2.7 \pm 0.6 \times 10^{-3}$
m_c/m_t	$2.5 \pm 0.2 \times 10^{-3}$	$2.4 \pm 0.2 \times 10^{-3}$	$2.3 \pm 0.2 \times 10^{-3}$
m_d/m_s	$5.1 \pm 0.7 \times 10^{-2}$	$5.1 \pm 0.7 \times 10^{-2}$	$5.1 \pm 0.7 \times 10^{-2}$
m_s/m_b	$1.9 \pm 0.2 \times 10^{-2}$	$1.7 \pm 0.2 \times 10^{-2}$	$1.6 \pm 0.2 \times 10^{-2}$
m_e/m_μ	$4.8 \pm 0.2 \times 10^{-3}$	$4.8 \pm 0.2 \times 10^{-3}$	$4.8 \pm 0.2 \times 10^{-3}$
m_μ/m_τ	$5.9 \pm 0.2 \times 10^{-2}$	$5.4 \pm 0.2 \times 10^{-2}$	$5.0 \pm 0.2 \times 10^{-2}$
Y_τ	0.070 ± 0.003	0.32 ± 0.02	0.51 ± 0.04
Y_b	0.051 ± 0.002	0.23 ± 0.01	0.37 ± 0.02
Y_t	0.48 ± 0.02	0.49 ± 0.02	0.51 ± 0.04

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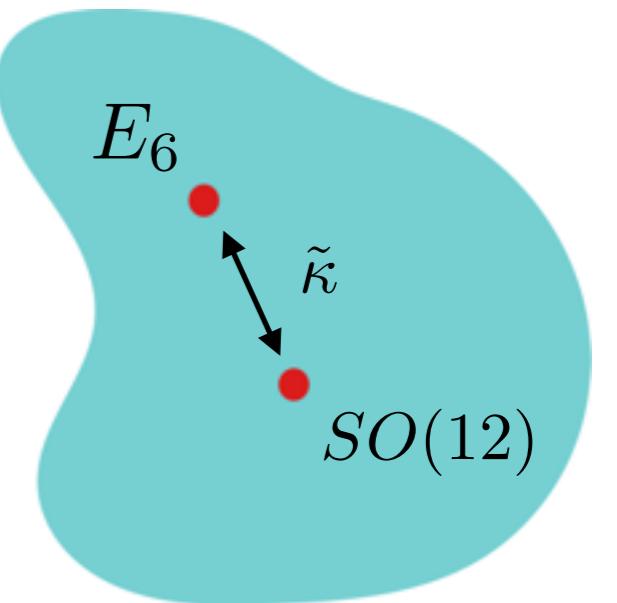
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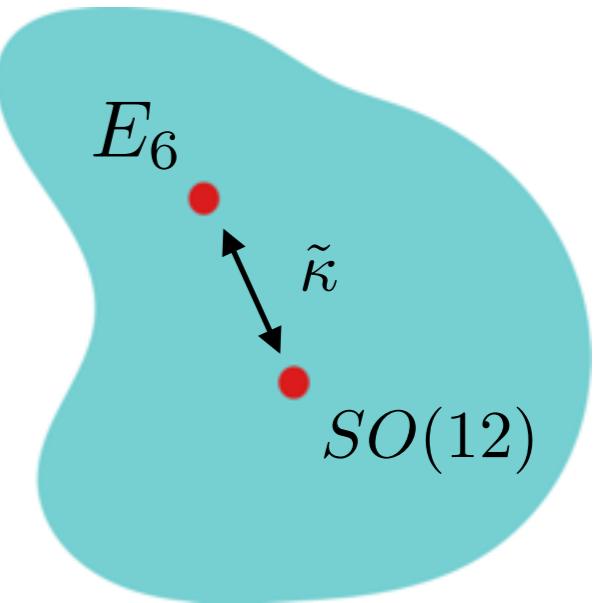
Separating the points

Small separation between Yukawa points



Separating the points

Small separation between Yukawa points



Change of wavefunction basis \longrightarrow Effect on CKM matrix

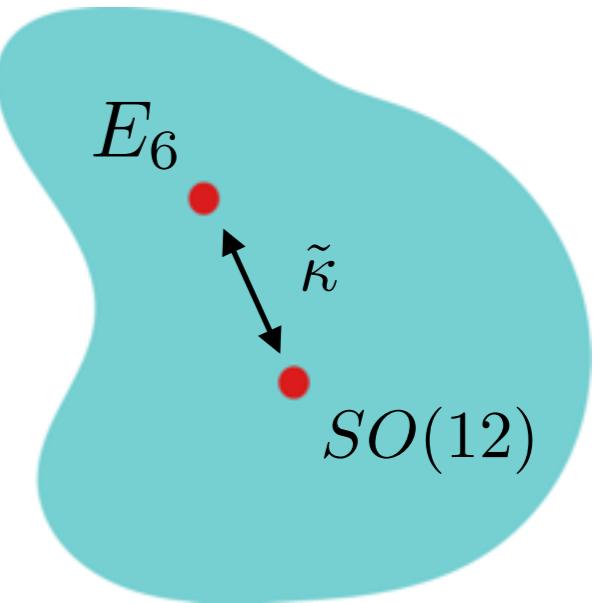
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Randall, Simmons-Duffin '09

$$|V_{tb}| \simeq 1 \longrightarrow |\tilde{\kappa}| \sim 10^{-2} - 10^{-3}$$

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$$|V_{tb}| \simeq 1 \longrightarrow |\tilde{\kappa}| \sim 10^{-2} - 10^{-3}$$

Only very small separation of points is possible in this scheme

Conclusions

- In F-theory models Yukawa matrix has rank 1
- Inclusion of non-perturbative effects increases the rank and may generate favourable hierarchies
- Not all E_8 models accommodate a good hierarchy
- A single model has hierarchical fermion masses, μ -term and neutrino masses
- Computation of physical coupling shows that GUT scale masses can be accommodated

Thank you!

Back up slides

Yukawa matrices

Up Yukawa matrix:

$$Y_U = \frac{\pi^2 \gamma_U \gamma_{10,3}^Q \gamma_{10,3}^U}{2\rho_m \rho_\mu} \begin{pmatrix} 0 & 0 & \tilde{\epsilon} \frac{\gamma_{10,1}^Q}{2\rho_\mu \gamma_{10,3}^U} \\ 0 & \tilde{\epsilon} \frac{\gamma_{10,2}^Q \gamma_{10,2}^U}{2\rho_\mu \gamma_{10,3}^Q \gamma_{10,3}^U} & 0 \\ \tilde{\epsilon} \frac{\gamma_{10,1}^U}{2\rho_\mu \gamma_{10,3}^U} & 0 & 1 \end{pmatrix} + \mathcal{O}(\tilde{\epsilon}^2)$$

Down Yukawa matrix:

$$Y_D = -\frac{\pi^2 \gamma_D \gamma_{10,3}^Q \gamma_{5,3}^D}{2d \rho_m \rho_\mu} \begin{pmatrix} 0 & \tilde{\epsilon} \tilde{\kappa} \frac{\gamma_{10,1}^Q \gamma_{5,2}^D}{d \rho_\mu^2 \gamma_{10,3}^Q \gamma_{5,3}^D} & \left(\frac{2\tilde{\kappa}^2}{\rho_\mu} - \frac{\tilde{\epsilon}}{d} \right) \frac{\gamma_{10,1}^Q}{2\rho_\mu \gamma_{10,3}^Q} \\ \tilde{\epsilon} \tilde{\kappa} \frac{\gamma_{10,2}^Q \gamma_{5,1}^D}{2d \rho_\mu^2 \gamma_{10,3}^Q \gamma_{5,3}^D} & -\tilde{\epsilon} \frac{\gamma_{10,2}^Q \gamma_{5,2}^D}{2d \rho_\mu \gamma_{10,3}^Q \gamma_{5,3}^D} & -\tilde{\kappa} \frac{\gamma_{10,2}^Q}{\rho_\mu \gamma_{10,3}^Q} \\ -\tilde{\epsilon} \frac{\gamma_{5,1}^D}{2d \rho_\mu \gamma_{5,3}^D} & 0 & 1 \end{pmatrix} + \mathcal{O}(\tilde{\epsilon}^2)$$

