Title: GUTs and Exceptional Branes in F-theory

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Abstract: Within the context of F-theory compactified on Calabi-Yau fourfolds, we describe a class of string theory vacua which contain several features necessary in supersymmetric grand unified models of particle physics. Focussing on a simple class of local Calabi-Yau fourfolds, we explain how the matter content and superpotential in four dimensions are determined by a topological gauge theory. Along these lines, we present some minimal examples of GUT models.

GUTs and Exceptional Branes in F-theory

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arXiv:0802.3391 [hep-th]
arXiv:0806.0102 [hep-th]
w/ C. Beasley & C. Vafa

Outline

- Motivation: GUTs and Type IIB
- Exceptional 7-branes: Spectrum & Yukawas
- Minimal GUTs
- Conclusions

Motivation

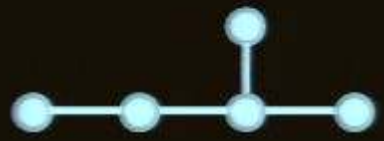
Standard Model/MSSM $\subset$ Strings?

Assume: 4d $\mathcal{N} = 1 \Rightarrow$ GUT, e.g.:

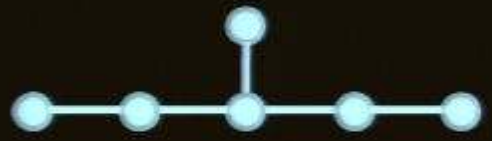
MSSM:

$E_4 = SU(5)$

$E_5 = SO(10)$



E_6



Strategy:

Top Down: Specify All Details in UV

Where to look first?

Bottom Up: Decouple as much of UV as possible

Too flexible?

Simplifying Assumptions:

1) A GUT exists

2) $M_{GUT}/M_{Planck} \neq 0$ BUT could *in principle* decouple

Surprisingly restrictive

Type IIB ∩ GUTs

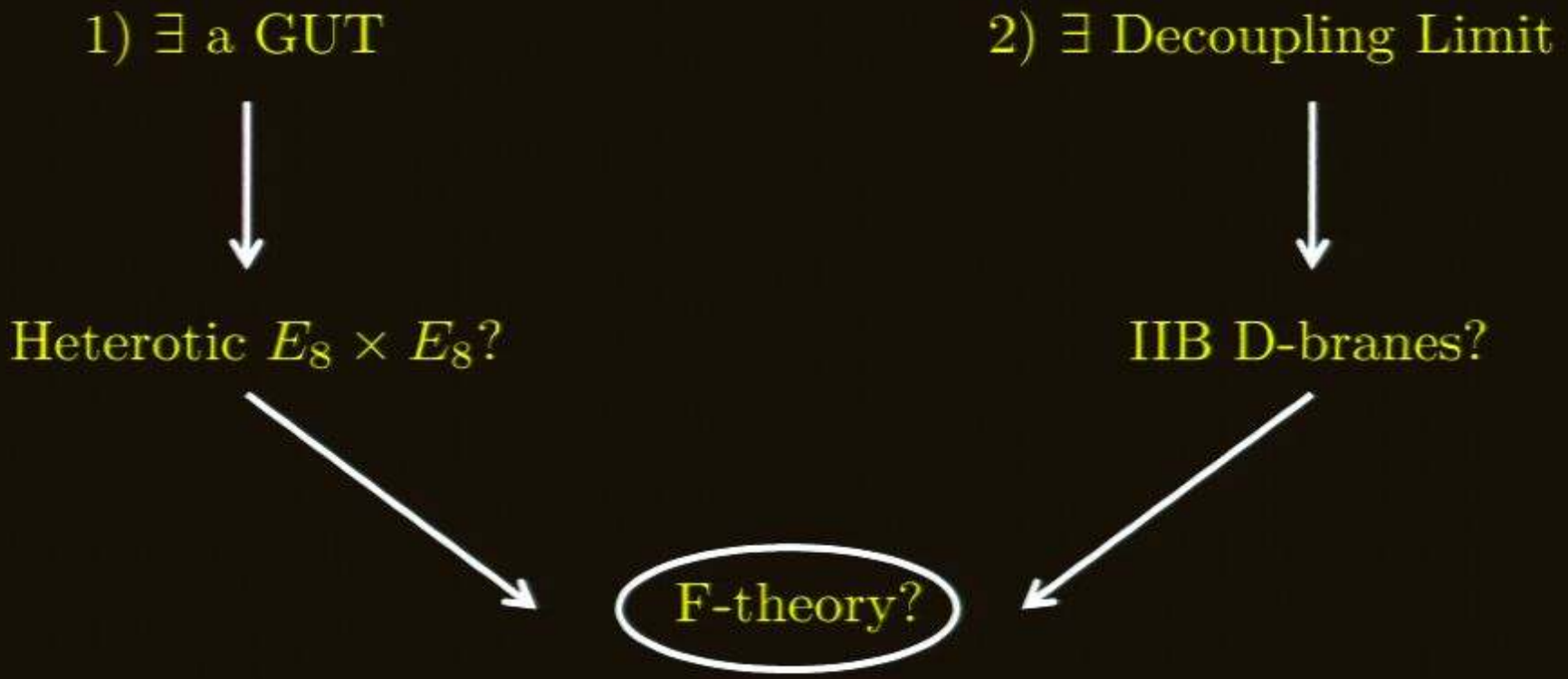
D-branes: localized gauge d.o.f ⇒ can decouple gravity

$g_s \to 0$ limit:

$SU(5)$: $5_H \times 10_M \times 10_M \to 0$ ← Requires ε_{ijklm}

$SO(10)$: No 16_M

No such problem in Heterotic $E_8 \times E_8$



Caveat: The vacua we find do NOT have a heterotic dual

Roadmap

- Motivation: GUTs and Type IIB

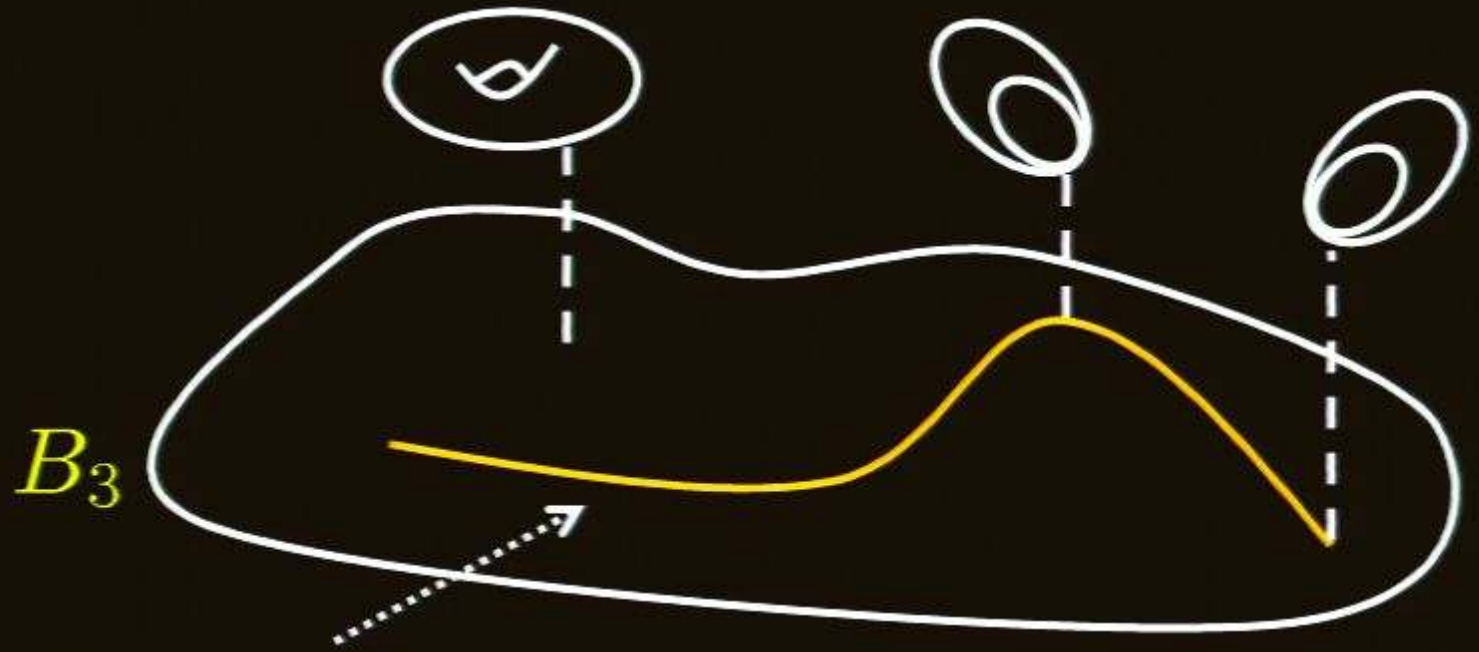
- Exceptional 7-branes:
  Spectrum & Yukawas

F-theory Review

F-theory $\Rightarrow$ geometrize $\tau_{IIB} = C_0 + ie^{-\phi}$

4d $\mathcal{N} = 1 \Rightarrow$ F / $R^{3,1} \times$ Elliptic CY_4

$CY_4 =$



$S =$ cplx surface $\subset B_3$

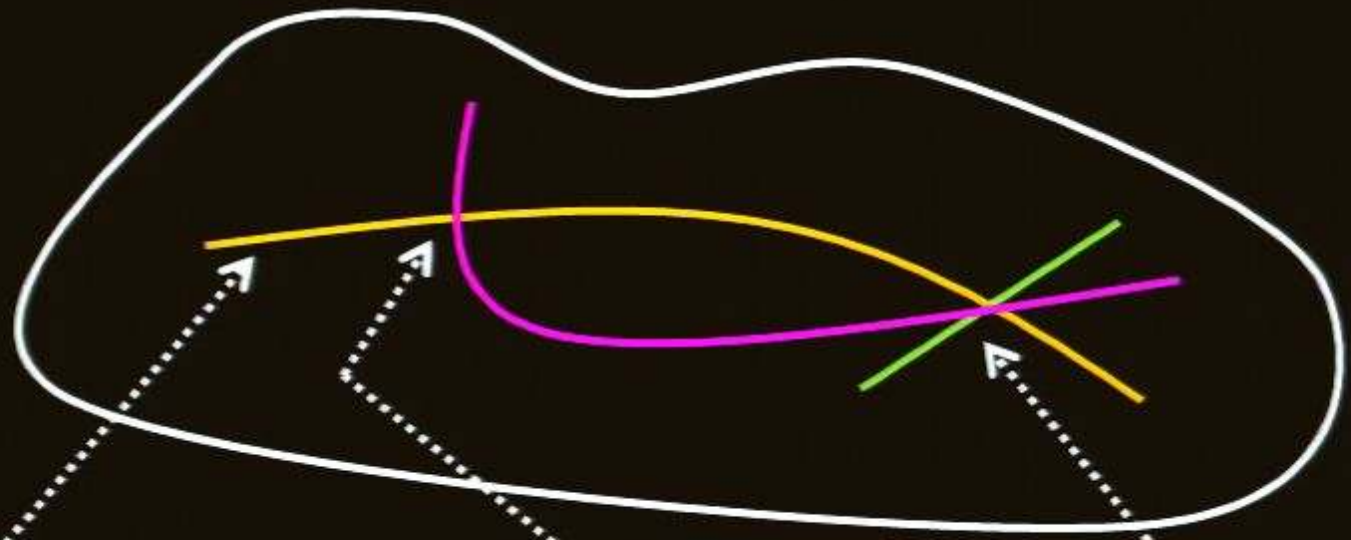
Locally: $CY_4 \sim S \times C^2/\Gamma_{ADE} \Rightarrow ADE$ Gauge Group

Setup

4d $\mathcal{N} = 1$ GUT, no gravity $\Rightarrow$ F / $R^{3,1} \times$ non-cpct CY_4

$CY_4 = T^2_{\tau_{IIB}} \rightarrow B_3$, B_3 non-cpct

B_3:



7-brane / S
(GUT lives here)

$7 \cap 7'$
Cplx Curve in S
6d hyper here
$\overline{5}, 10 \in SU(5)$, $16 \in SO(10)$...

$7 \cap 7' \cap 7''$
Point in S
$\Rightarrow W_{4d}$

Superpotential

	S	Σ	p
dim_C	2	1	0

Treat 8d and 6d fields as

4d $\mathcal{N} = 1$ superfields

$$W = W_S + (W_{\Sigma_1} + \cdots) + (W_{p_1} + \cdots)$$

SSS: $$W_S = \int_S Tr(\overline{\partial} A_{(0,1)} + A_{(0,1)} \wedge A_{(0,1)}) \wedge \Phi_{(2,0)}$$

$S\Sigma\Sigma$: $$W_\Sigma = \int_\Sigma \Lambda^c_{(1/2,0)} (\overline{\partial} + A_{(0,1)} + A'_{(0,1)}) \Lambda_{(1/2,0)}$$

$\Sigma\Sigma\Sigma$: $$W_p = \Lambda_1 \Lambda_2 \Lambda_3 |_p$$

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(see also Bershadsky, Johansen, Pantev, Sadov '97)

4d Spectrum & Yukawas

$$G_S \xrightarrow{\text{instanton}} \Gamma_S \times \cancel{H_S}$$

4d matter $\Longleftrightarrow$ zero modes in instanton background

S Modes: $\overline{\partial}_A \Psi = 0$

Σ Modes: $\overline{\partial}_{A+A'} \sigma = 0$

$\Rightarrow$ Index Computation

$$W_{eff} = W[\Phi_0, A_0, \Lambda_0] + \cdots$$

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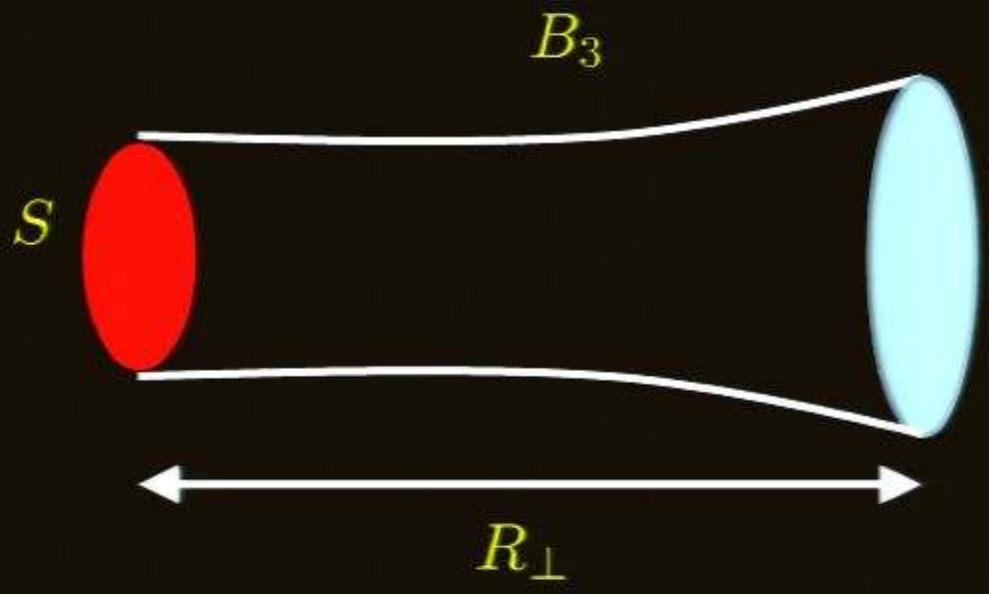
Roadmap

- Exceptional 7-branes:
  Spectrum & Yukawas

- Minimal GUTs

Consequences of Decoupling

$\exists$ limit $M_{GUT}/M_{pl} \to 0 \Rightarrow S$ Shrinkable: Surprisingly Restrictive



Shrinkable S = "del Pezzo" $\Rightarrow$ only 10 choices, $c_1 > 0$

No Adjoints & No Wilson lines Beasley JJH Vafa '08

A Minimal Spectrum

$$G_S = SU(5) \xrightarrow{U(1)_Y \text{ instanton}} SU(3) \times SU(2) \times U(1)_Y$$

No bulk exotics $\Rightarrow$ unique internal flux

Higgs Curves: $\int_{\Sigma_H} F_{U(1)_Y} \neq 0$:

$$5_H \rightarrow \underbrace{H_u}_{\text{in}} + \underbrace{(3,1)_{-1/3}}_{\text{out}}$$

$$\overline{5}_H \rightarrow H_d + (\overline{3},1)_{+1/3}$$

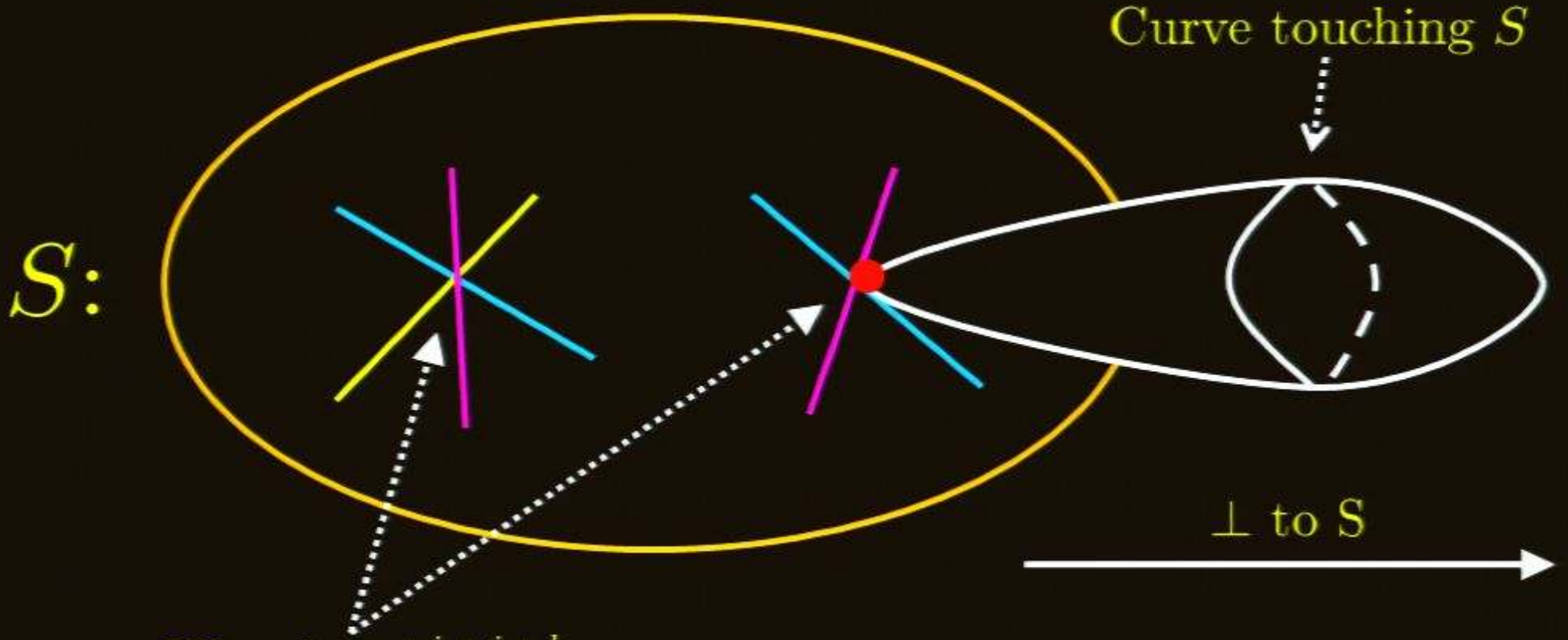
Matter Curve(s): $\int_{\Sigma_M} F_{U(1)_Y} = 0$:

$$3 \times \overline{5}_M$$

$$3 \times 10_M$$

in

Yukawas:



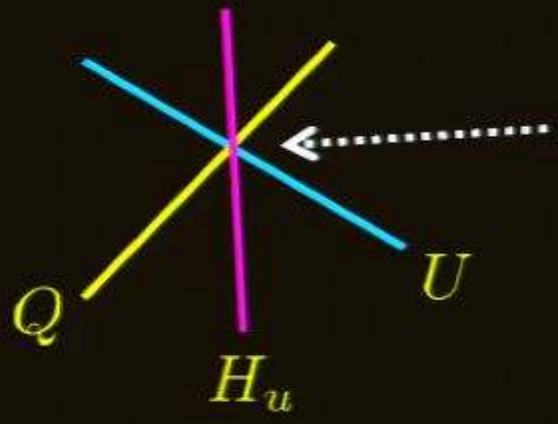
$$W \supset \lambda_{ijk}\Lambda^i\Lambda^j\Lambda^k$$

$$\lambda_{ijk} = \sum_p \psi_i(p)\psi_j(p)\psi_k(p)$$

Yukawas Inside S:

Example: $W_{up} = \lambda_{ij} Q^i U^j H_u$

One overlap: $\lambda = \mathcal{O}(1)$

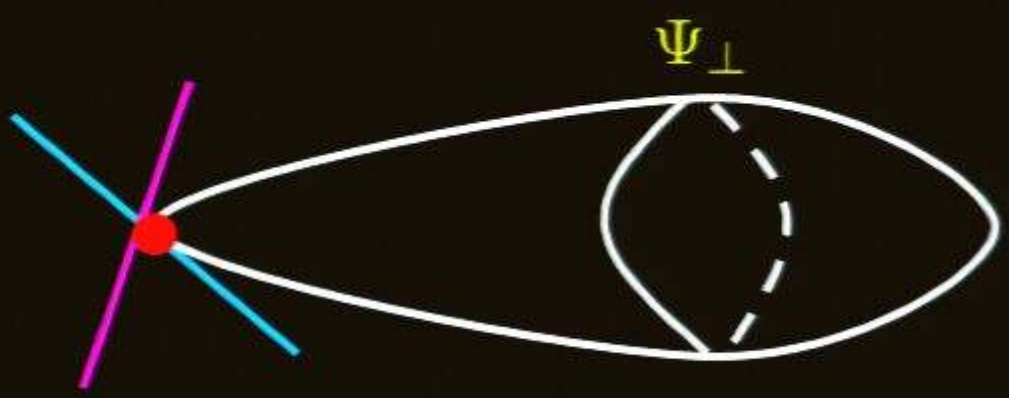


$\lambda_{ij} = \psi^i_Q(0)\psi^j_U(0)\psi_{H_u}(0) =$ outer product

$$\text{Mass Matrix} = \begin{bmatrix} 0 & & \\ & 0 & \\ & & m \end{bmatrix}$$

More overlaps $\Rightarrow$ higher rank

Gauge Singlet Wave Functions



$\mathcal{R} \sim -M_{GUT}^2$ for del Pezzo

$$\left(4\frac{\partial^2}{\partial z \partial \overline{z}} + \mathcal{F} - \tfrac{1}{2}\mathcal{R}\right)\Psi_\perp = 0$$

$$\Psi_\perp \sim \exp\left(\pm m_{eff}^2 |z|^2\right)$$

Attraction:	Repulsion:
$\Psi_\perp(0) \sim \mathcal{O}(1)$	$\Psi_\perp(0) \sim \exp\left(-\#R_\perp^2/R_{GUT}^2\right)$
$\Rightarrow$ as if inside S	$\Rightarrow$ Suppressed Yukawas

Vector-Like Pairs:

Vector-like pairs couple via singlets outside S

μ problem: $W \supset \mu H_u H_d$ BUT $\mu \ll M_{GUT}$?

$$W \supset \varepsilon \times s H_u H_d \xrightarrow{\langle s \rangle \gg M_{weak}} \mu H_u H_d$$

$\mu \sim M_{weak}$

Similar for Dirac neutrinos

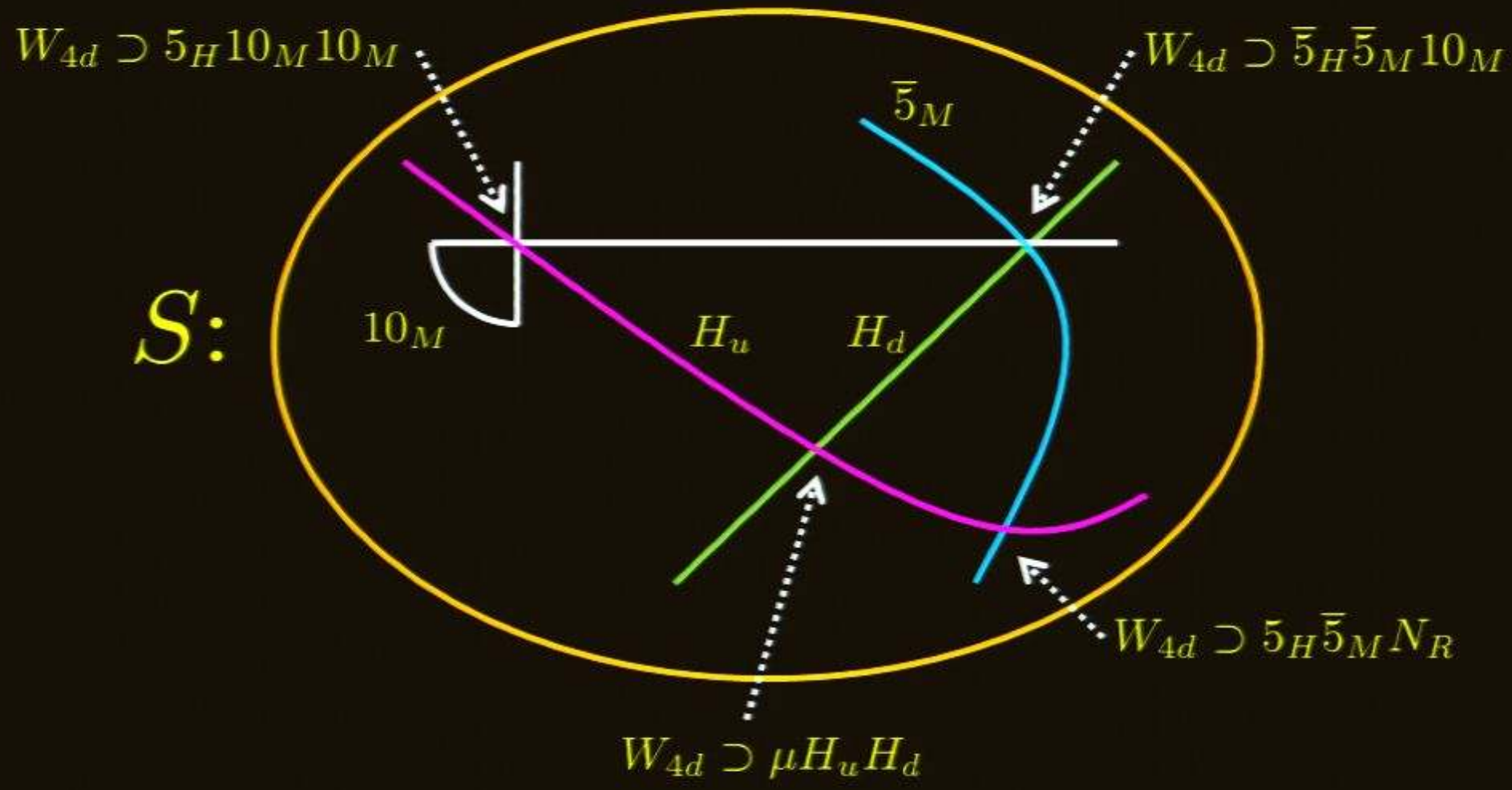
$W \supset \varepsilon \times H_u L N_R$

(Seesaw also available)

Conclusions/Future Directions

- GUT $\cap$ IIB $\Rightarrow$ F-theory 7-branes
- "Decoupling Criterion" $\Rightarrow$ Extra Structure
- ~~SUSY~~?
- Compact CY_4?

SU(5) Example


$W_{4d} \supset 5_H 10_M 10_M$
$W_{4d} \supset \bar{5}_H \bar{5}_M 10_M$
$\bar{5}_M$
S:
10_M
H_u
H_d
$W_{4d} \supset 5_H \bar{5}_M N_R$
$W_{4d} \supset \mu H_u H_d$