

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

Jonathan J. Heckman

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

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.:

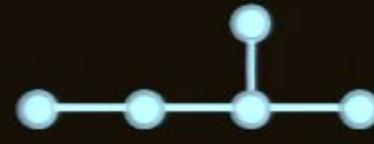
MSSM:



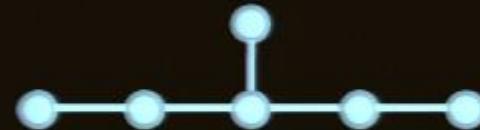
$E_4 = SU(5)$



$E_5 = SO(10)$



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 \cap GUTs

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

$g_s \rightarrow 0$ limit:

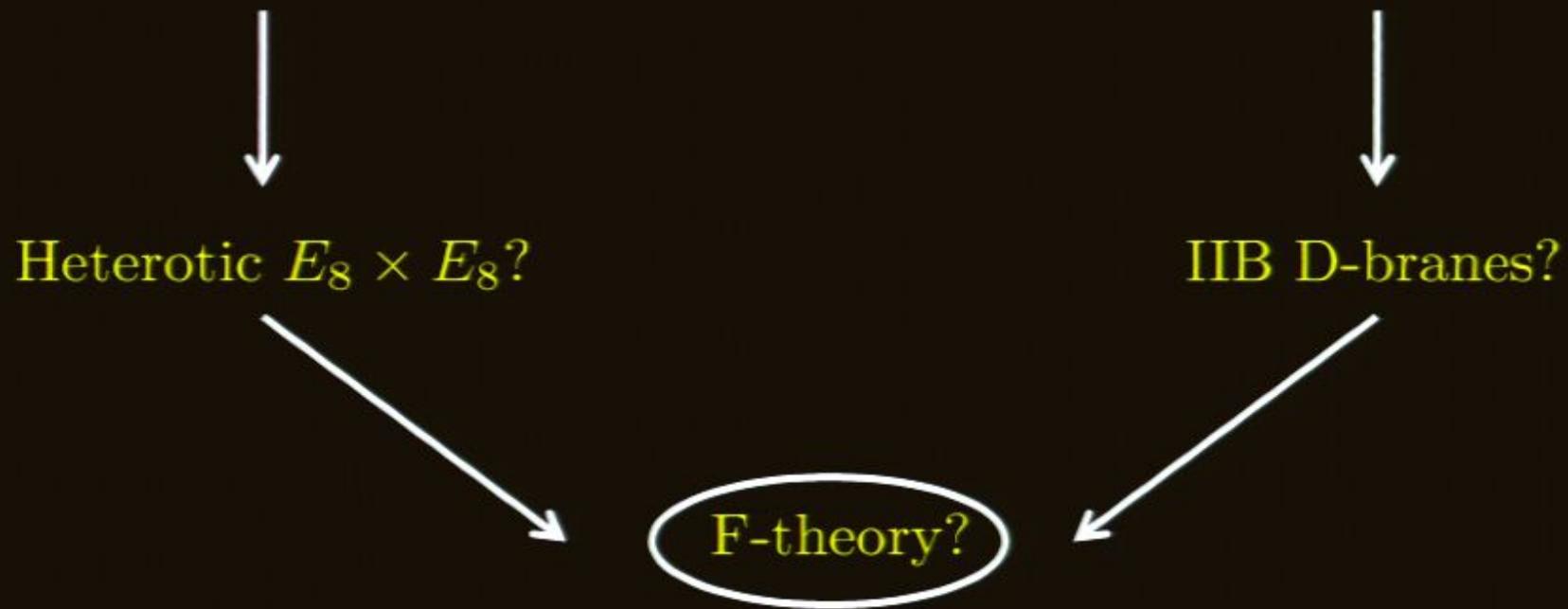
$SU(5): 5_H \times 10_M \times 10_M \rightarrow 0$  Requires ε_{ijklm}

$SO(10)$: No 16_M

No such problem in Heterotic $E_8 \times E_8$

1) \exists a GUT

2) \exists Decoupling Limit



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

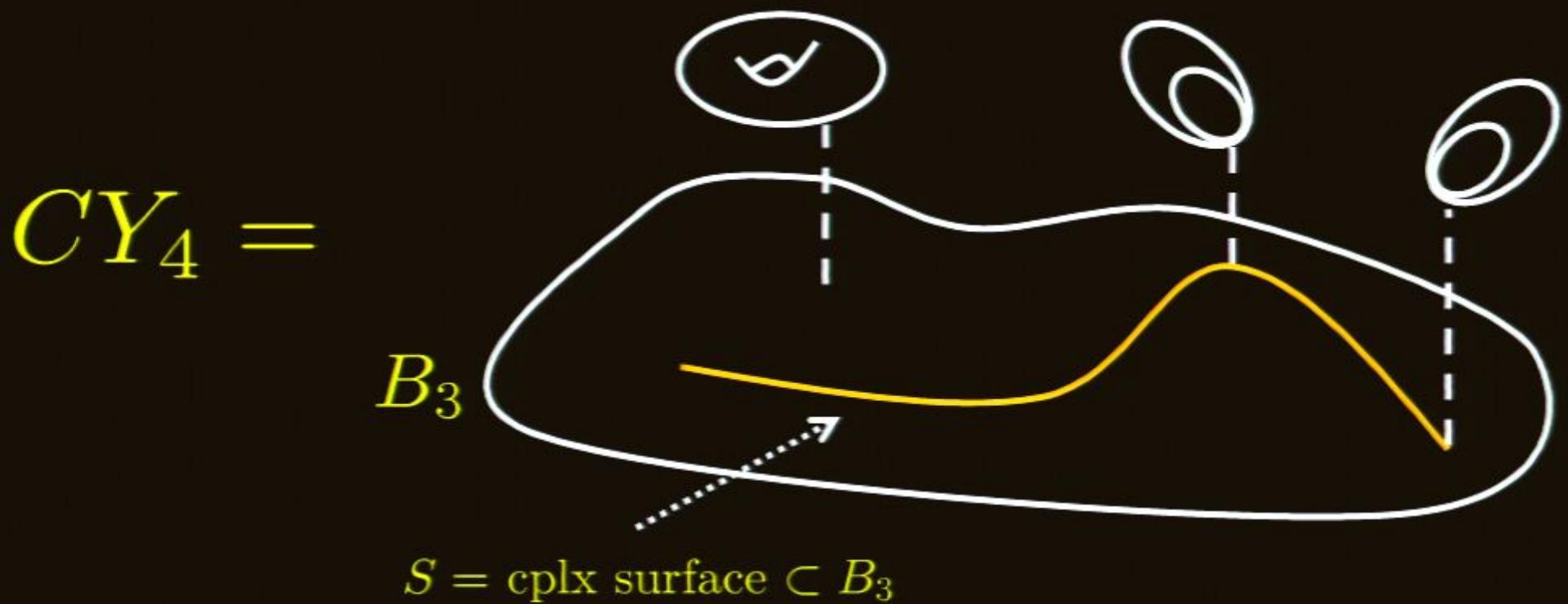
Roadmap

- Motivation: GUTs and Type IIB
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- 

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



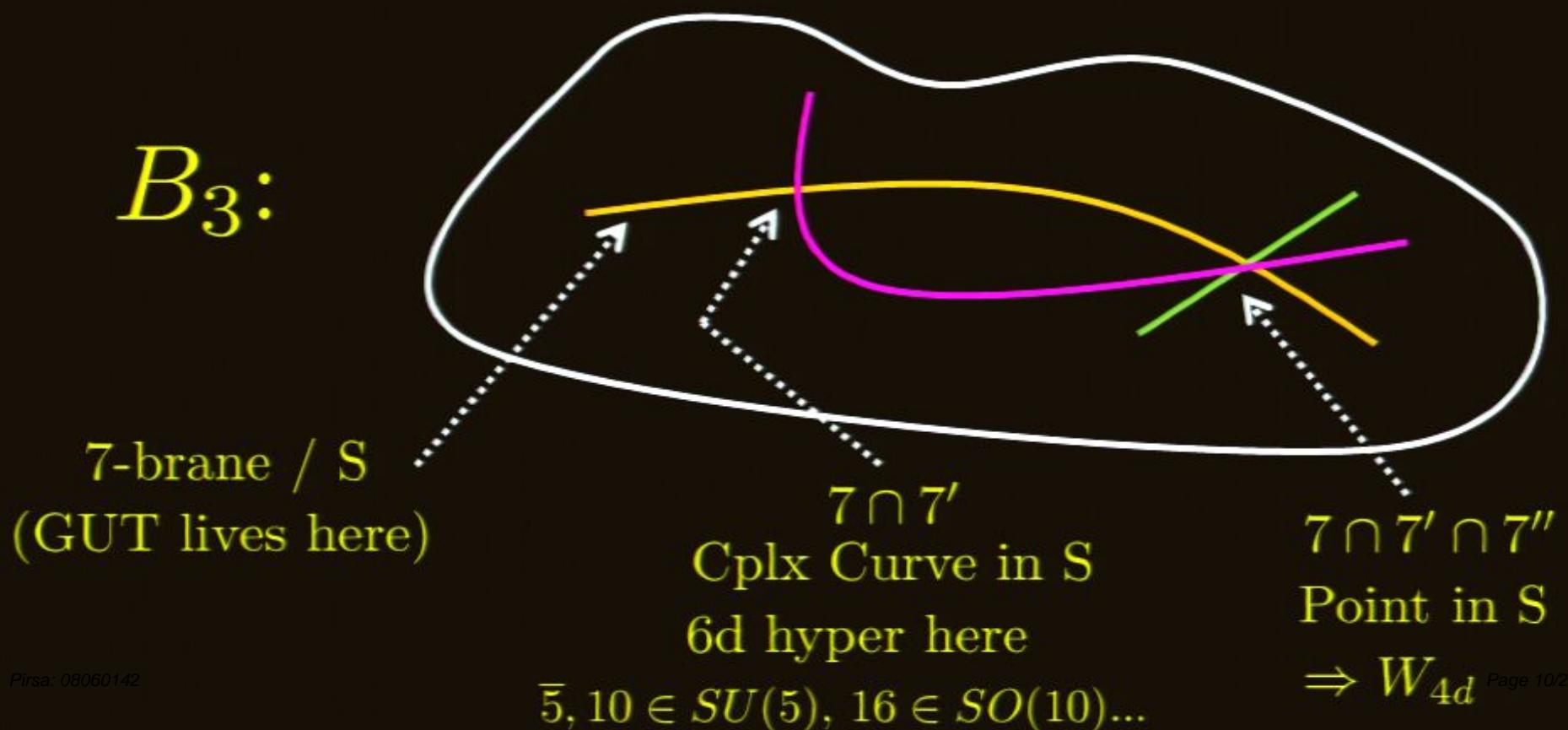
$$S = \text{cplx surface} \subset B_3$$

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-cpt CY_4

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



Superpotential

	S	Σ	p
dim_C	2	1	0

Treat 8d and 6d fields as
4d $\mathcal{N} = 1$ superfields

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

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

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

$\Sigma\Sigma\Sigma:$ $W_p = \Lambda_1 \Lambda_2 \Lambda_3|_p$ Beasley JJH Vafa '08

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

4d Spectrum & Yukawas

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

4d matter \iff zero modes in instanton background

S Modes: $\bar{\partial}_A \Psi = 0$] \Rightarrow Index Computation
Σ Modes: $\bar{\partial}_{A+A'} \sigma = 0$]

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

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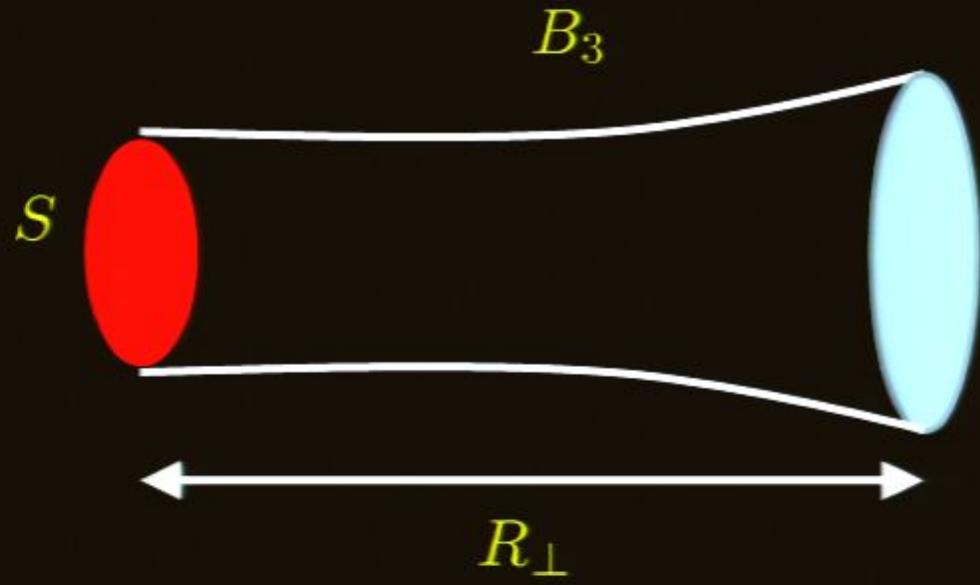
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Consequences of Decoupling

\exists limit $M_{GUT}/M_{pl} \rightarrow 0 \Rightarrow S$ 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

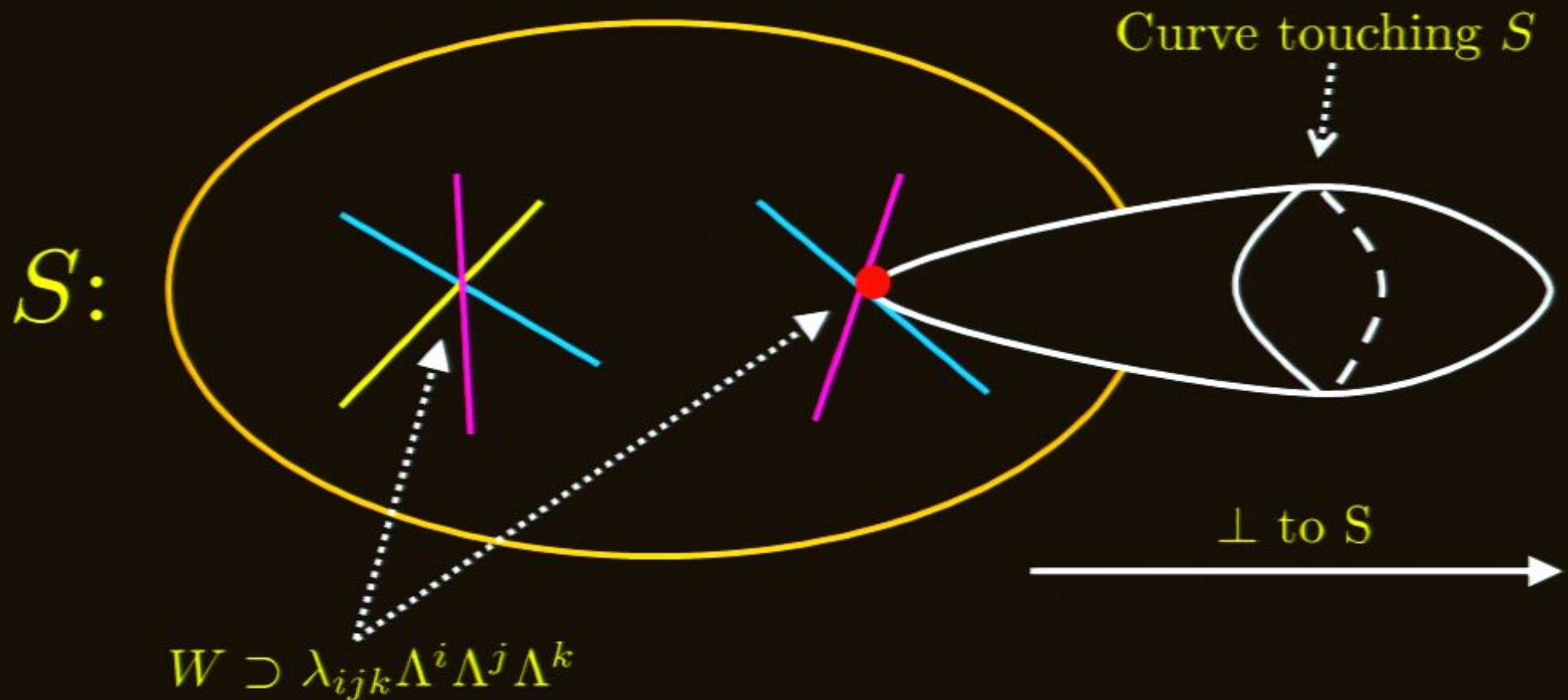
Higgs Curves: $\int_{\Sigma_H} F_{U(1)_Y} \neq 0 :$

$$\begin{array}{ccc} 5_H & \rightarrow & [H_u] + [(3, 1)_{-1/3}] \\ & & \text{in} \\ \overline{5}_H & \rightarrow & [H_d] + [(\overline{3}, 1)_{+1/3}] \\ & & \text{out} \end{array}$$

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

$$\begin{array}{c} 3 \times \overline{5}_M \\ 3 \times 10_M \end{array}$$

Yukawas:

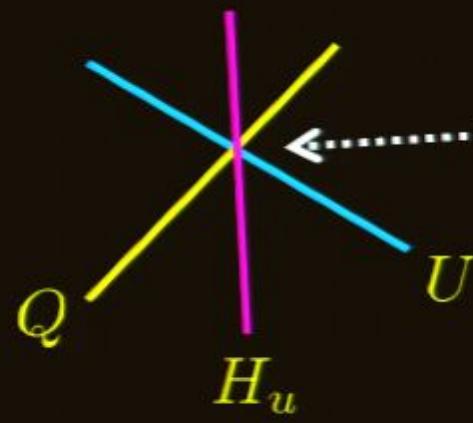


$$\lambda_{ijk} = \sum_p \psi_i(p) \psi_j(p) \psi_k(p)$$

Yukawas Inside S:

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

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



$\lambda_{ij} = \psi_Q^i(0) \psi_U^j(0) \psi_{H_u}(0) = \text{outer product}$

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

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

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

Attraction:

$$\Psi_{\perp}(0) \sim \mathcal{O}(1)$$

\Rightarrow as if inside S

Repulsion:

$$\Psi_{\perp}(0) \sim \exp\left(-\#R_{\perp}^2/R_{GUT}^2\right)$$

\Rightarrow Suppressed Yukawas

Vector-Like Pairs:

Vector-like pairs couple via singlets outside S

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

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

\uparrow $\mu \sim M_{weak}$

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

