Title: A Fertile Patch in the Heterotic Landscape

Date: May 01, 2009 01:00 PM

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Abstract: In this talk I describe the progress that we have made in the constuction of string vacua with many of the features of the minimal supersymmetric standard model (MSSM).

A Fertile Patch in the Heterotic Landscape

Stuart Raby

Perimeter Institute
May 1, 2009

THE OHIO STATE UNIVERSITY
DEPARTMENT OF PHYSICS

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Kobayashi, Raby, Zhang

hep-ph/0403065 , hep-ph/040909

Buchmuller, Hamaguchi, Lebedev & Ratz

hep-ph/0511035, hep-ph/0512326

Lebedev, Nilles, Raby, Ramos-Sanchez, Ratz,

Vaudrevange & Wingerter hep-th/0611095,

hep-th/0611203, 0708.2691(hep-th)

Kobayashi, Nilles, Ploeger, Raby & Ratz

hep-ph/0611020

Dundee, Raby & Wingerter

arXiv:0805.4186 (hep-th)

Dundee & Raby arXiv:0808.0992 (hep-th)

Virtues of SUSY GUTs

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- Neutrino masses and mixing via See-Saw

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String Model Building

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Gauge-Higgs unification $Y_{top} = g_{GUT}$

Exact R-parity

Vector-like exotics & extra U(

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Gauge coupling unification & more ...

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SUSY solution at M_s

100's moduli (geometric & more)

gauge & Yukawa couplings fcns. of moduli

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tune to desired values

Standard Model =

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Where would you look ??

In this landscape ?

Standard Model =

Where would you look ??

In this landscape ?

Or in a golf course !

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Outline

- Perform focused search "Mini Landscape"

  Lebedev, Nilles, Raby, Ratz, Ramos-Sanchez, Vaudrevange & Wingerter

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- Consider properties of one "Benchmark" model

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See what MSSM-like means !

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Compactify 6D on $(T^2)^3$

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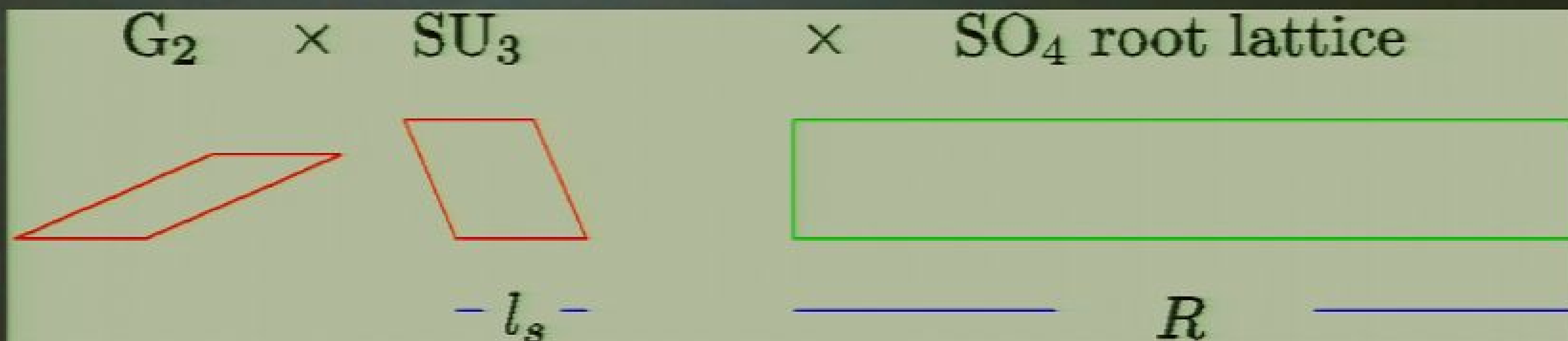

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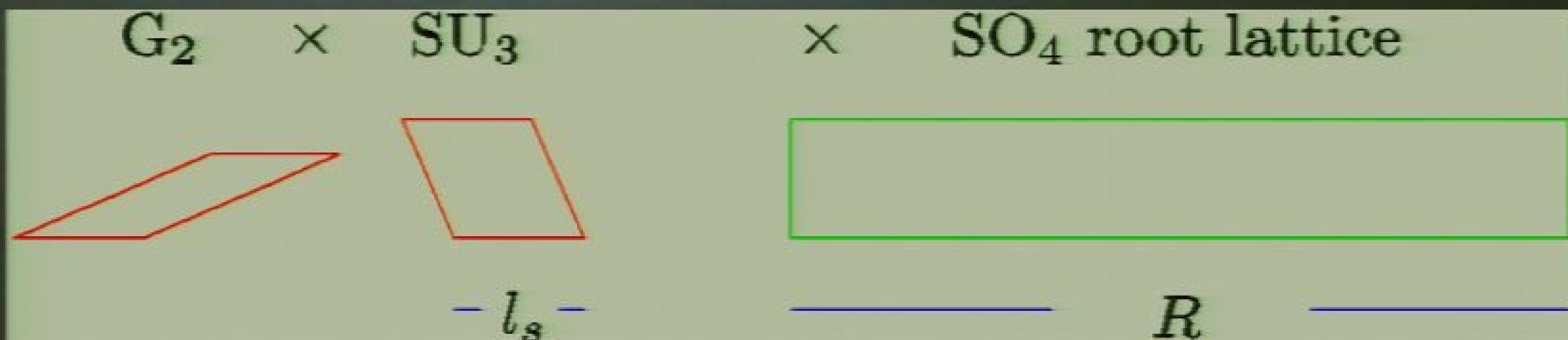

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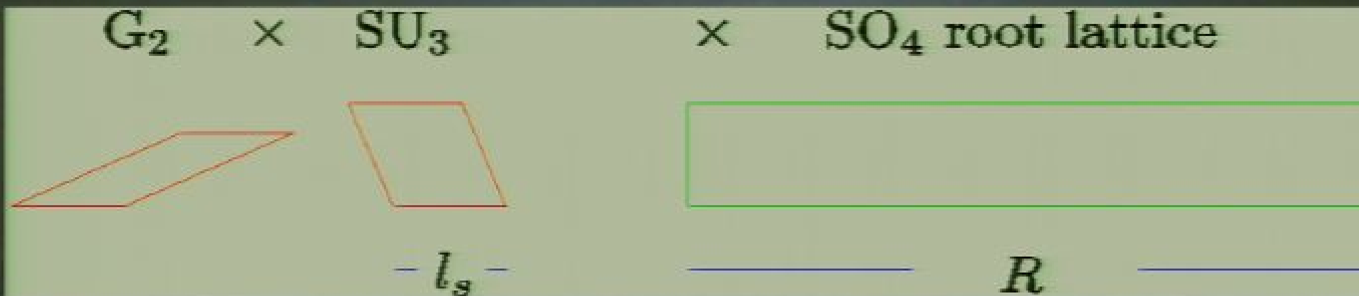
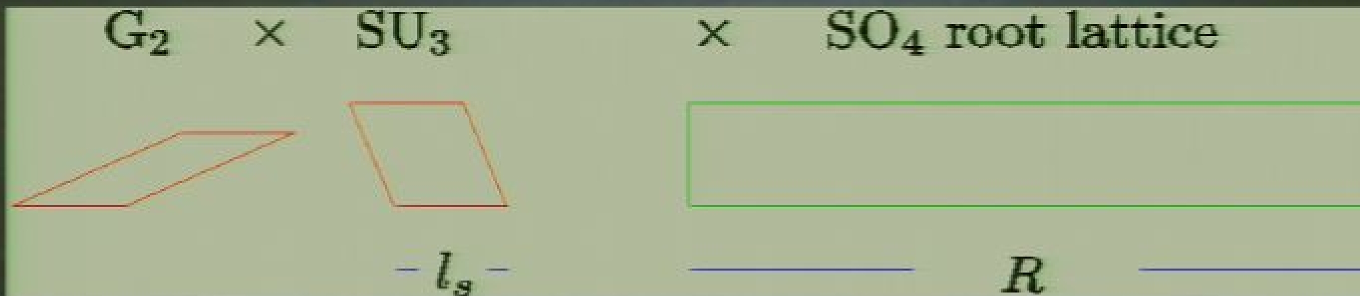
Z_6 embedded in $E_8 \times E_8$ gauge lattice
as shift V_6 : consistent with mod. inv. !



Untwisted

$$v_6 = \tfrac{1}{6}(1, 2, -3, 0), \quad Z^i \rightarrow \exp\left(2\pi i v_6^i\right) Z^i$$



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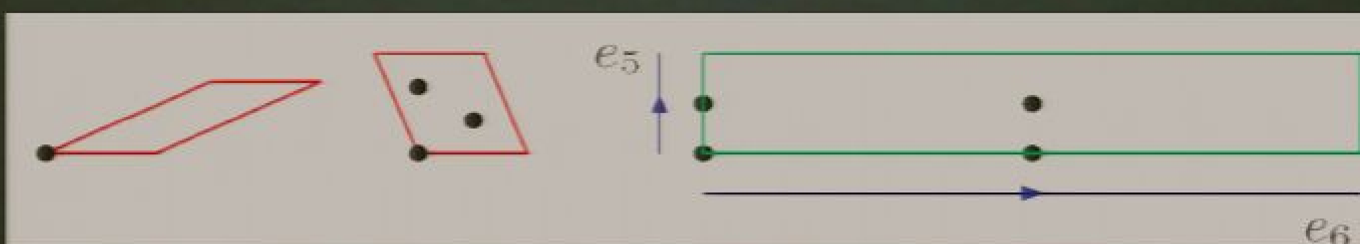
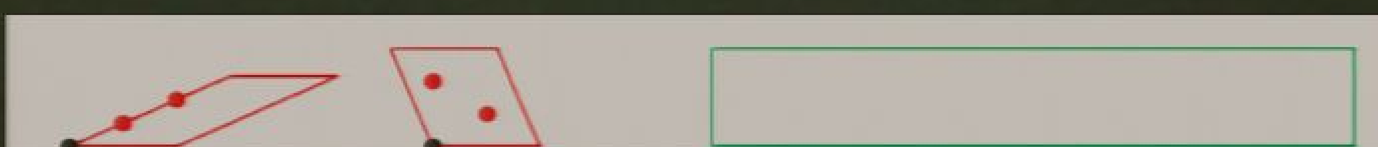
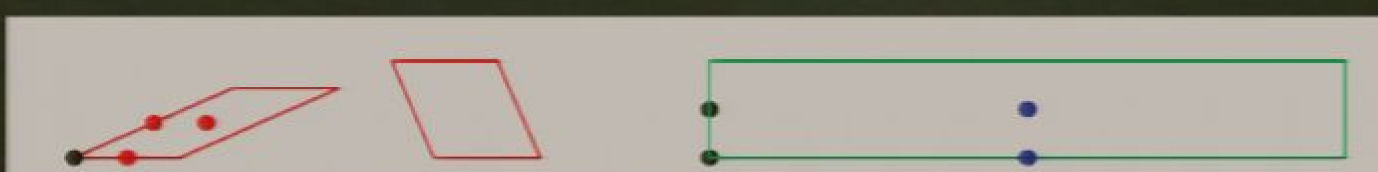


$T_{1,5}$ twisted



$T_{2,4}$ twisted



T_3 twisted

Mini-Landscape search Z_6-II orbifold

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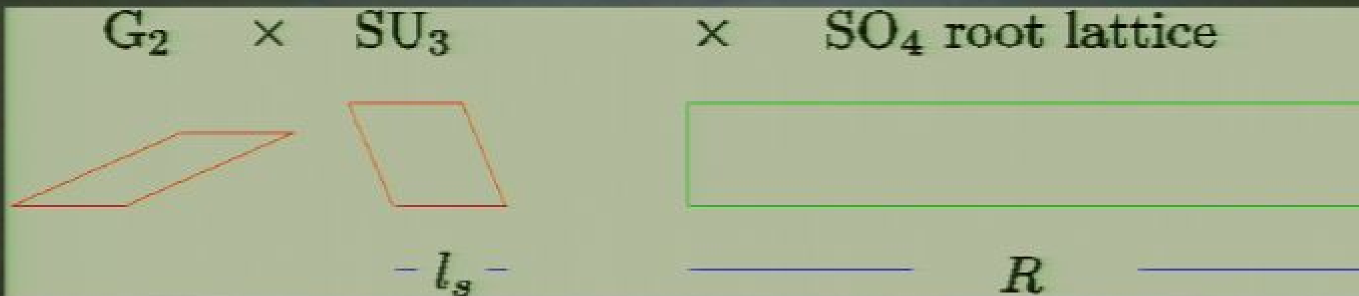

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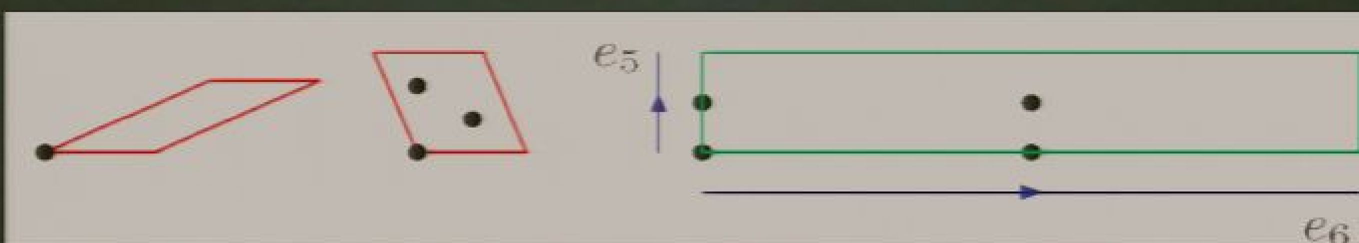

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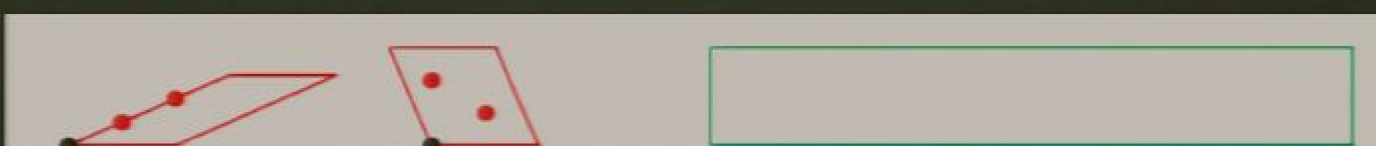

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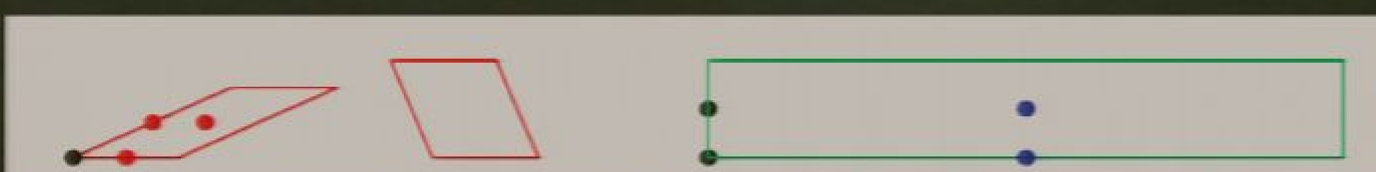

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6. Select models with 3 SM families + Higgses + **vector-like** exotics

Mini-Landscape search
LNRRRVW

criterion	$V^{SO(10),1}$	$V^{SO(10),2}$	$V^{E_6,1}$	$V^{E_6,2}$
(2) inequivalent models with 2 Wilson lines	22,000	7,800	680	1,700
(3) SM gauge group $\subset$ SU(5) $\subset$ SO(10) ($\subset E_6$)	3563	1163	27	63
(4) 3 net $(\mathbf{3}, \mathbf{2})$	1170	492	3	32
(5) non–anomalous $U(1)_Y \subset SU(5)$	528	234	3	22
(6) spectrum = 3 generations + vector-like	128	90	3	2

Table 1: Statistics of $\mathbb{Z}_6$-II orbifolds based on the shifts $V^{SO(10),1}$, $V^{SO(10),2}$, $V^{E_6,1}$, $V^{E_6,2}$ with two Wilson lines.

218 Models with 3 families, Higgs & vector-like exotics

Road to the MSSM with R-parity

LNRRRVW - 0708.2691(hep-th)

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7. Check dimension 5 B & L violating ops.

D = 0

criterion	$V^{\mathrm{SO}(10),1}$	$V^{\mathrm{SO}(10),2}$	total
(6) spectrum = 3 generations + vector-like	128	90	218
(6') exotics decouple with arbitrary singlet VEVs at order $\tilde{s}^6$	106	85	191
(6") exotics decouple with singlet VEVS along D-flat directions	106	84	190

Generalized R parity

	q	l	H_u	H_d	$\bar{U}\bar{D}\bar{D}$	$Q\bar{D}L$	$LL\bar{E}$	LH_u
B-L	1/3	-1	0	0	-1	-1	-1	-1
$\tilde{R}$	$e^{i\alpha\pi/3}$	$e^{-i\alpha\pi}$	1	1	$e^{-i\alpha\pi}$	$e^{-i\alpha\pi}$	$e^{-i\alpha\pi}$	$e^{-i\alpha\pi}$

$$\tilde{R} = e^{i\alpha\pi(B-L)}$$

Forbid Dim 2 & 3 operators ⇒ $\alpha \neq 2Z$

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$$\tilde{R} = e^{i\alpha\pi(B-L)} \qquad (B-L)\langle\phi\rangle = f\langle\phi\rangle \;\Rightarrow\; \alpha = 2/f$$

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Family Reflection symmetry or Matter parity → $\alpha = 3$, $f = 2/3$

Construct model w/ Generalized R parity

Identify "suitable" B–L

- standard for SM particles
- vector-like on exotics
- maximal no. SM singlets w/

$$f = 0, 2, 2/3, 2/5, 4/5, 2/7, 4/7, ...$$

Results

criterion	$V^{SO(10),1}$	$V^{SO(10),2}$	total
(6) spectrum = 3 generations + vector-like	128	90	218
(7) heavy top	72	37	109
(8) exotics decouple at order 8 (arbitrary vevs)	56	32	88
(9) "suitable" $B-L$ × multiple choices (below)	34	5	39
(10) State in SM family; Different $(B-L)$s	3447	144	3591
(11) inequivalent $\{\ \tilde{S}\ \}$	85	8	93
(12) $\langle\tilde{S}\rangle$ break all $U(1)$s	42	0	42
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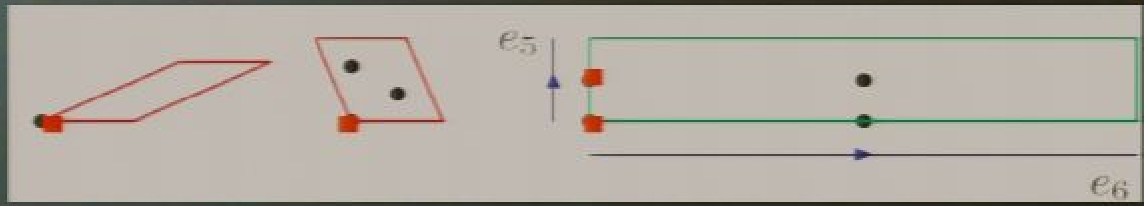
$P \in E(8)$ Gauge lattice **Benchmark Model**

$$P = (n_1, n_2, \ldots, n_8),\ (n_1 + \tfrac{1}{2}, n_2 + \tfrac{1}{2}, \ldots, n_8 + \tfrac{1}{2})$$

$$n_i \in \mathbb{Z} \quad (i = 1, \ldots, 8) \qquad \sum_{i=1}^{8} \mathrm{n}_i = 2\mathbb{Z}$$

Local SO(10) GUT



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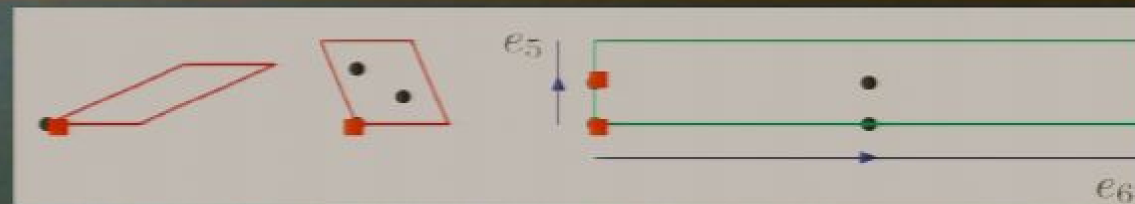
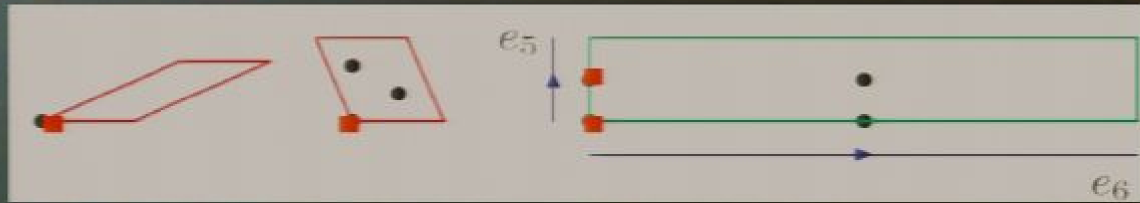


$$P^2=2, \quad P\cdot V_6=\mathbb{Z}$$

$$P=\left(0,0,0,\underline{\pm1,\pm1,0,0,0}\right) \oplus \left(0,\pm1,\pm1,0,0,0,0,0\right)$$

$$\Rightarrow \quad \text{Local SO(10)} \otimes \text{SO(4) GUT}$$

Local SO(10) GUT



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$$\Rightarrow \quad \text{Local } SO(10) \otimes SO(4) \text{ GUT}$$

Require massless SO(10) spinors at T_1 fixed points

Orbifold GUTs

First consider $(T^2)^3/Z_3 \; + \; W_3$

(Wilson line in SU_3 torus)

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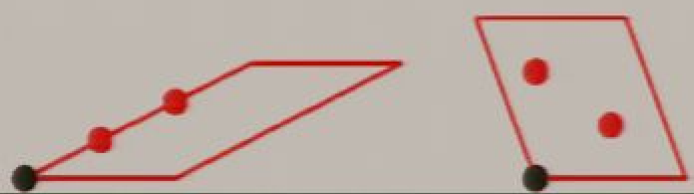

$$\left(V,\Phi\right) \in 35 \;\Rightarrow\; SU(6)\text{ adjoint}$$

$$\left(20+20^c\right) \oplus 18\left(6+6^c\right)$$

Massless modes

From Untwisted sector +

(G_2, SU_3) twisted sector

Orbifold GUTs

Consider massless Untwisted sector

$P^2 = 2$

Orbifold GUTs

Consider massless Untwisted sector

$P^2 = 2$

GSO projection

$$V_6 = (\tfrac{1}{3}, \tfrac{1}{2}, \tfrac{1}{2}, 0, 0, 0, 0, 0), \quad V_3 = 2V_6$$

$$P \cdot V_3 - r \cdot v_3 \in \mathbb{Z}, \qquad r = \left(\underline{0, 1, 0, 0}\right)$$

$$v_3 = \tfrac{1}{3}(1, -1, 0, 0) \qquad \text{twist}$$

Orbifold GUTs

Consider massless Untwisted sector

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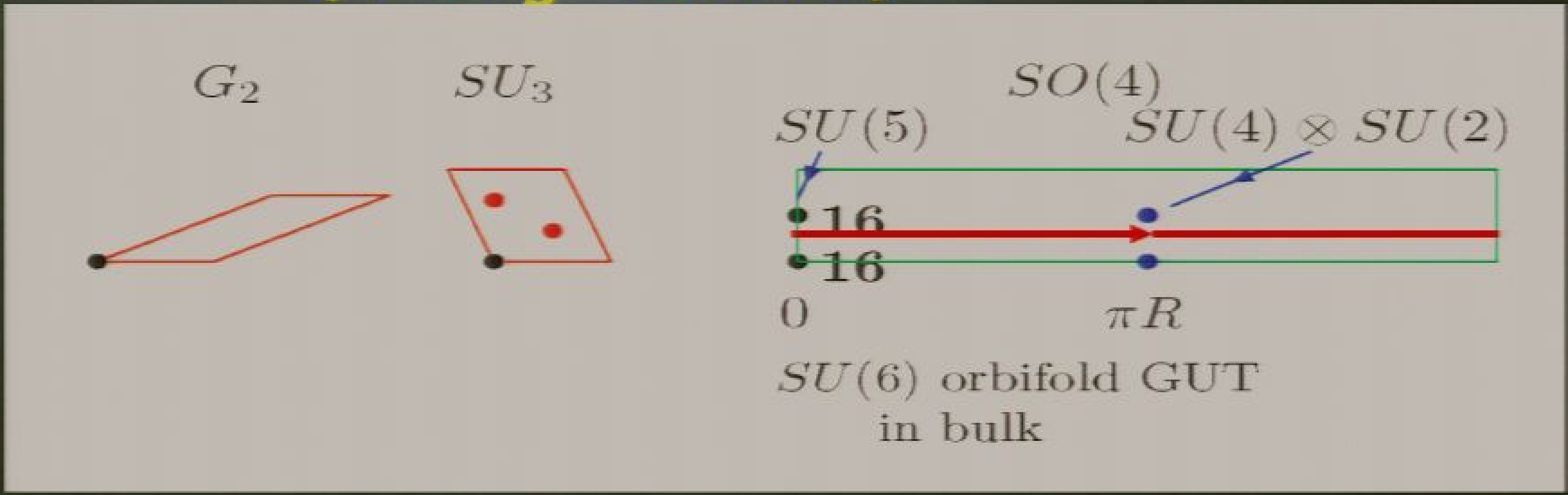
U_3 Gauge

Consider $P \cdot V_3 = \mathbb{Z}$ Gauge & U_3

$$V_3 = 2V_6 = (\tfrac{2}{3}, -1, -1, 0, 0, 0, 0, 0)$$

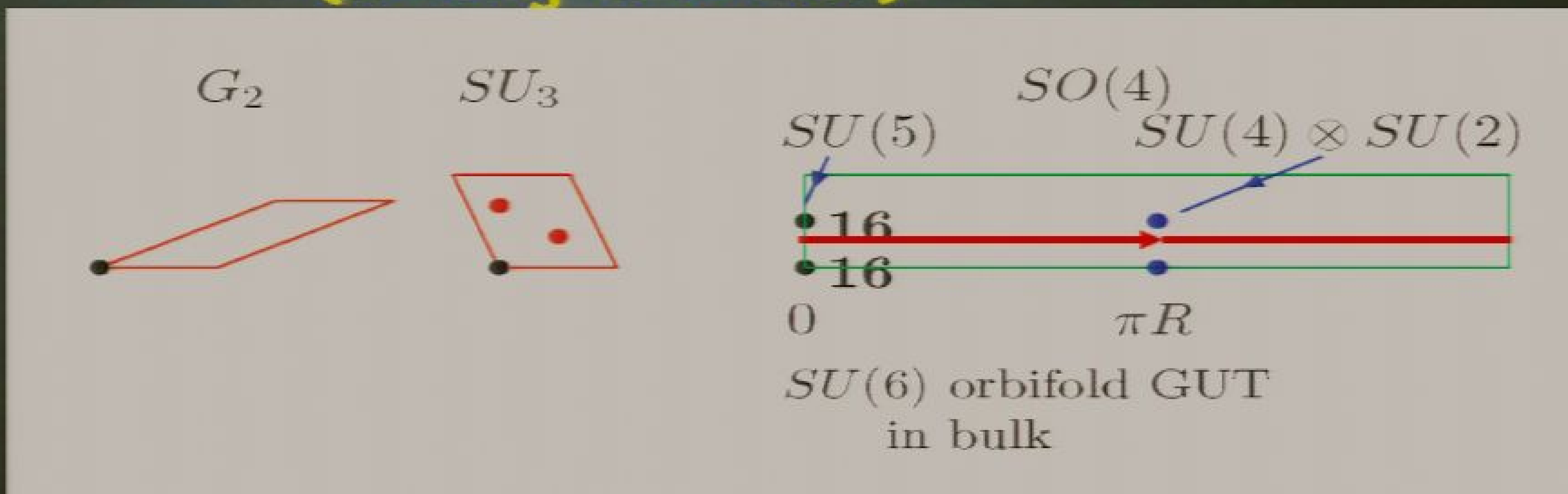
$$P = \quad (0, \underrightarrow{\pm 1, \pm 1, 0, 0, 0, 0, 0}) \qquad \mathrm{SO}(14)$$

Then add Z_2 orbifold + W_2
(in long direction)



$SU(6) \rightarrow SU(5)$

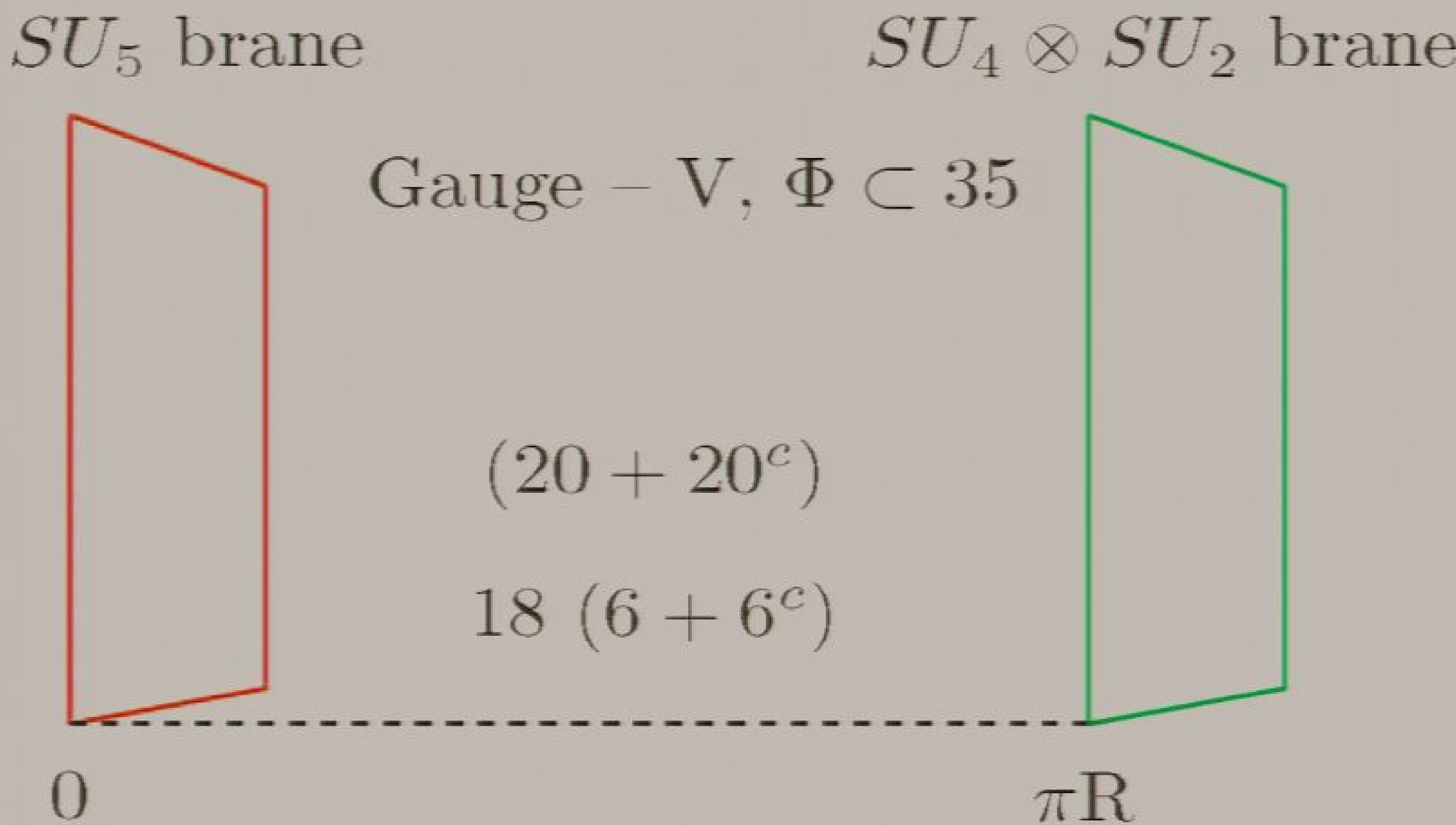
Then add Z_2 orbifold + W_2
(in long direction)



P (V_2)

SU(6) → SU(5) → SU(3)xSU(2)xU(1)

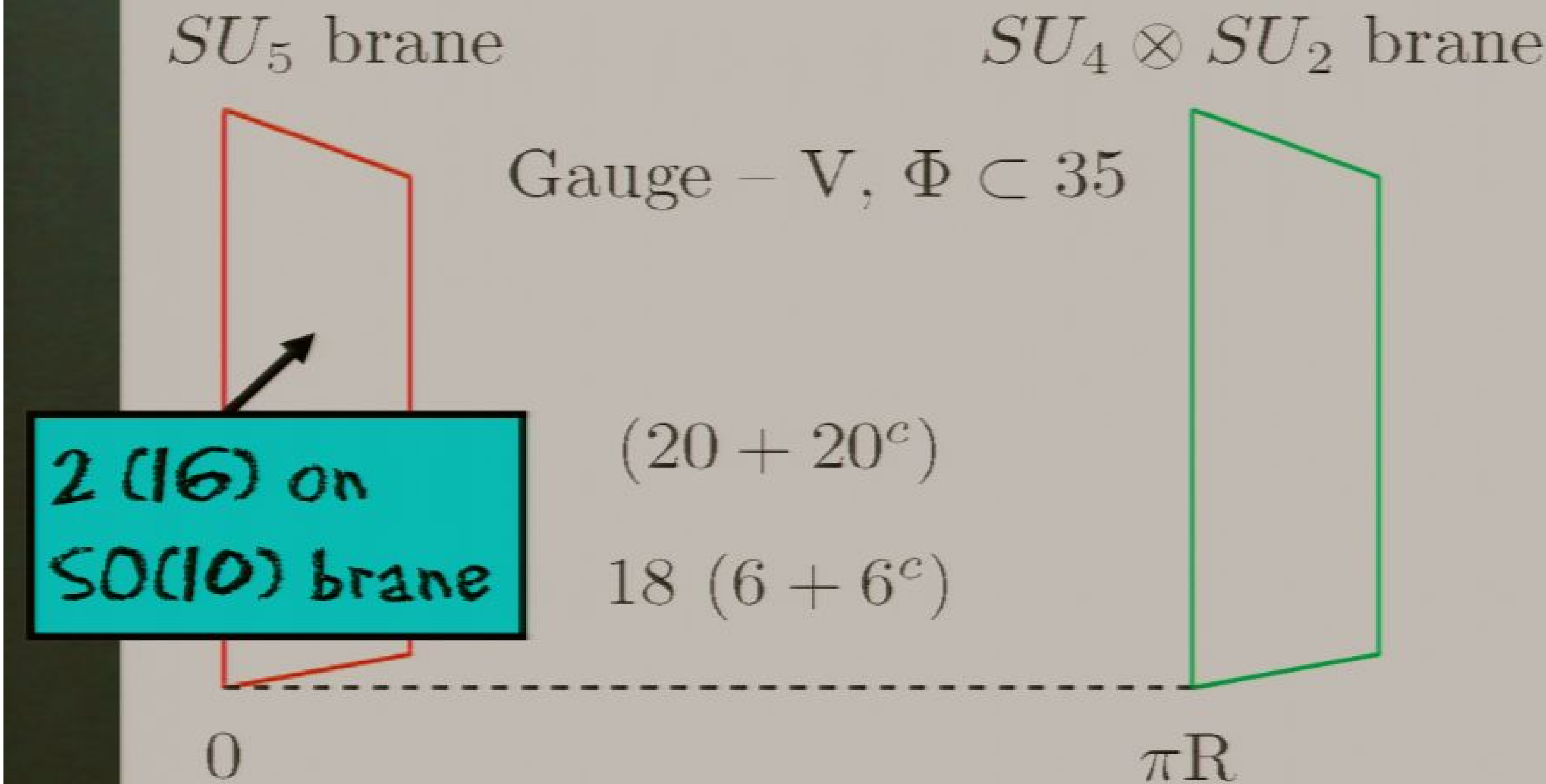
$SU(6)$ Orbifold GUT



Third family & Higgs in BULK

$$\begin{pmatrix} V_{++}^{(3\times3)} & V_{+-}^{(3\times2)} & V_{-+}^{(3\times1)} \\ V_{+-}^{(2\times3)} & V_{++}^{(2\times2)} & V_{--}^{(2\times1)} \\ V_{-+}^{(1\times3)} & V_{--}^{(1\times2)} & V_{++}^{(1\times1)} \end{pmatrix} \quad \begin{pmatrix} \Phi_{--}^{(3\times3)} & \Phi_{-+}^{(3\times2)} & \Phi_{+-}^{(3\times1)} \\ \Phi_{-+}^{(2\times3)} & \Phi_{--}^{(2\times2)} & \Phi_{++}^{(2\times1)} = \mathrm{H}_u \\ \Phi_{+-}^{(1\times3)} & \Phi_{++}^{(1\times2)} = \mathrm{H}_d & \Phi_{--}^{(1\times1)} \end{pmatrix}$$

$SU(6)$ Orbifold GUT



Third family & Higgs in BULK

$$\begin{pmatrix} V_{++}^{(3\times3)} & V_{+-}^{(3\times2)} & V_{-+}^{(3\times1)} \\ V_{+-}^{(2\times3)} & V_{++}^{(2\times2)} & V_{--}^{(2\times1)} \\ V_{-+}^{(1\times3)} & V_{--}^{(1\times2)} & V_{++}^{(1\times1)} \end{pmatrix} \quad \begin{pmatrix} \Phi_{--}^{(3\times3)} & \Phi_{-+}^{(3\times2)} & \Phi_{+-}^{(3\times1)} \\ \Phi_{-+}^{(2\times3)} & \Phi_{--}^{(2\times2)} & \Phi_{++}^{(2\times1)} = \mathrm{H}_u \\ \Phi_{+-}^{(1\times3)} & \Phi_{++}^{(1\times2)} = \mathrm{H}_d & \Phi_{--}^{(1\times1)} \end{pmatrix}$$

Third family & Higgs in BULK

$$\begin{pmatrix} V^{(3\times3)}_{++} & V^{(3\times2)}_{+-} & V^{(3\times1)}_{-+} \\ V^{(2\times3)}_{+-} & V^{(2\times2)}_{++} & V^{(2\times1)}_{--} \\ V^{(1\times3)}_{-+} & V^{(1\times2)}_{--} & V^{(1\times1)}_{++} \end{pmatrix} \quad \begin{pmatrix} \Phi^{(3\times3)}_{--} & \Phi^{(3\times2)}_{-+} & \Phi^{(3\times1)}_{+-} \\ \Phi^{(2\times3)}_{-+} & \Phi^{(2\times2)}_{--} & \Phi^{(2\times1)}_{++} \boxed{= \mathrm{H}_u} \\ \Phi^{(1\times3)}_{+-} & \Phi^{(1\times2)}_{++} \boxed{= \mathrm{H}_d} & \Phi^{(1\times1)}_{--} \end{pmatrix}$$

$$(20 + 20^c) \Rightarrow \mathrm{Q}_3 + \overline{\mathrm{t}} + \overline{\tau}$$

$$2\left(6 + 6^c\right) \Rightarrow \mathrm{L}_3 + \overline{\mathrm{b}}$$

D_4 family symmetry

$$D_4 = \{\pm 1, \pm\sigma_1, \pm\sigma_3, \mp i\sigma_2\}$$

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} : f_1 \leftrightarrow f_2 \qquad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} : f_2 \leftrightarrow -f_2$$

geometry

space group sel. rule

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$$\begin{pmatrix} f_1 \\ f_2 \end{pmatrix}$$ doublet

Discrete Family Symmetries

Kobayashi, Nilles, Ploeger, Raby & Ratz
hep-ph/0611020

Discrete Family Symmetries

Kobayashi, Nilles, Ploeger, Raby & Ratz
hep-ph/0611020

See also: D_4 phenomenology
Ko, Kobayashi, Park & Raby arXiv:0704.2807

Benchmark model

#	irrep	label	#	irrep	label
3	$(\mathbf{3},\mathbf{2};\mathbf{1},\mathbf{1})_{(1/3,1/3)}$	q_i	3	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-4/3,-1/3)}$	$\bar{u}_i$
3	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(2,1)}$	$\bar{e}_i$	8	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(0,*)}$	m_i
4	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,1/3)}$	d_i
4	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{\ell}_i$
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,0)}$	ϕ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,0)}$	$\bar{\phi}_i$
6	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,2/3)}$	$\bar{\delta}_i$	6	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-2/3)}$	δ_i
14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,*)}$	s_i^+	14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1,*)}$	s_i^-
16	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$	13	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,1)}$	$\bar{\eta}_i$	5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,-1)}$	η_i
10	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,0)}$	h_i	2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})_{(0,0)}$	y_i
6	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(0,*)}$	f_i	6	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(0,*)}$	$\bar{f}_i$
2	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(-1,-1)}$	f_i^-	2	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(1,1)}$	$\bar{f}_i^+$
4	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,\pm 2)}$	χ_i	32	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,0)}$	s_i^0
2	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1/3,2/3)}$	$\bar{v}_i$	2	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(1/3,-2/3)}$	v_i

Table 1: Spectrum. The quantum numbers under $SU(3)\times SU(2)\times[SU(4)\times SU(2)']$ are shown, hypercharge and B-L charge appear as subscript.

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4	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,-1/3)}$	$\bar{d}_i$	1	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,1/3)}$	d_i
4	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{\ell}_i$
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,0)}$	ϕ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,0)}$	$\bar{\phi}_i$
6	$(\overline{\mathbf{3}},\mathbf{1};\mathbf{1},\mathbf{1})_{(2/3,2/3)}$	$\bar{\delta}_i$	6	$(\mathbf{3},\mathbf{1};\mathbf{1},\mathbf{1})_{(-2/3,-2/3)}$	δ_i
14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(1,*)}$	s_i^+	14	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(-1,*)}$	s_i^-
16	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,1)}$	$\bar{n}_i$	13	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{1})_{(0,-1)}$	n_i
5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,1)}$	$\bar{\eta}_i$	5	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,-1)}$	η_i
10	$(\mathbf{1},\mathbf{1};\mathbf{1},\mathbf{2})_{(0,0)}$	h_i	2	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{2})_{(0,0)}$	y_i
6	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(0,*)}$	f_i	6	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(0,*)}$	$\bar{f}_i$
2	$(\mathbf{1},\mathbf{1};\mathbf{4},\mathbf{1})_{(-1,-1)}$	f_i^-	2	$(\mathbf{1},\mathbf{1};\overline{\mathbf{4}},\mathbf{1})_{(1,1)}$	$\bar{f}_i^+$
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4	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,-1)}$	ℓ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,1)}$	$\bar{\ell}_i$
1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,0)}$	ϕ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,0)}$	$\bar{\phi}_i$
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$\tilde{S}$

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1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(-1,0)}$	ϕ_i	1	$(\mathbf{1},\mathbf{2};\mathbf{1},\mathbf{1})_{(1,0)}$	$\bar{\phi}_i$
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$\tilde{S}$

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$$\overline{UDD},\ LL\overline{E},\ QL\overline{D},\ LH_u$$

μ term

$$\left\langle W_0\left(\tilde{S}\right)\right\rangle \phi_1 \overline{\phi_1}$$

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Yukawa couplings

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$\mu = 0$ in flat space SUSY limit

Yukawa couplings

$$Y_u = \begin{pmatrix} \tilde{s}^5 & \tilde{s}^5 & \tilde{s}^5 \\ \tilde{s}^5 & \tilde{s}^5 & \tilde{s}^5 \\ \tilde{s}^6 & \tilde{s}^6 & 1 \end{pmatrix}, \qquad Y_d = \begin{pmatrix} \tilde{s}^5 & \tilde{s}^5 & 0 \\ \tilde{s}^5 & \tilde{s}^5 & 0 \\ \tilde{s}^6 & \tilde{s}^6 & 0 \end{pmatrix},$$

Not realistic - yet

$$Y_e = \begin{pmatrix} \tilde{s}^5 & \tilde{s}^5 & \tilde{s}^6 \\ \tilde{s}^5 & \tilde{s}^5 & \tilde{s}^6 \\ \tilde{s}^6 & \tilde{s}^6 & 0 \end{pmatrix}$$

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Neutrino masses

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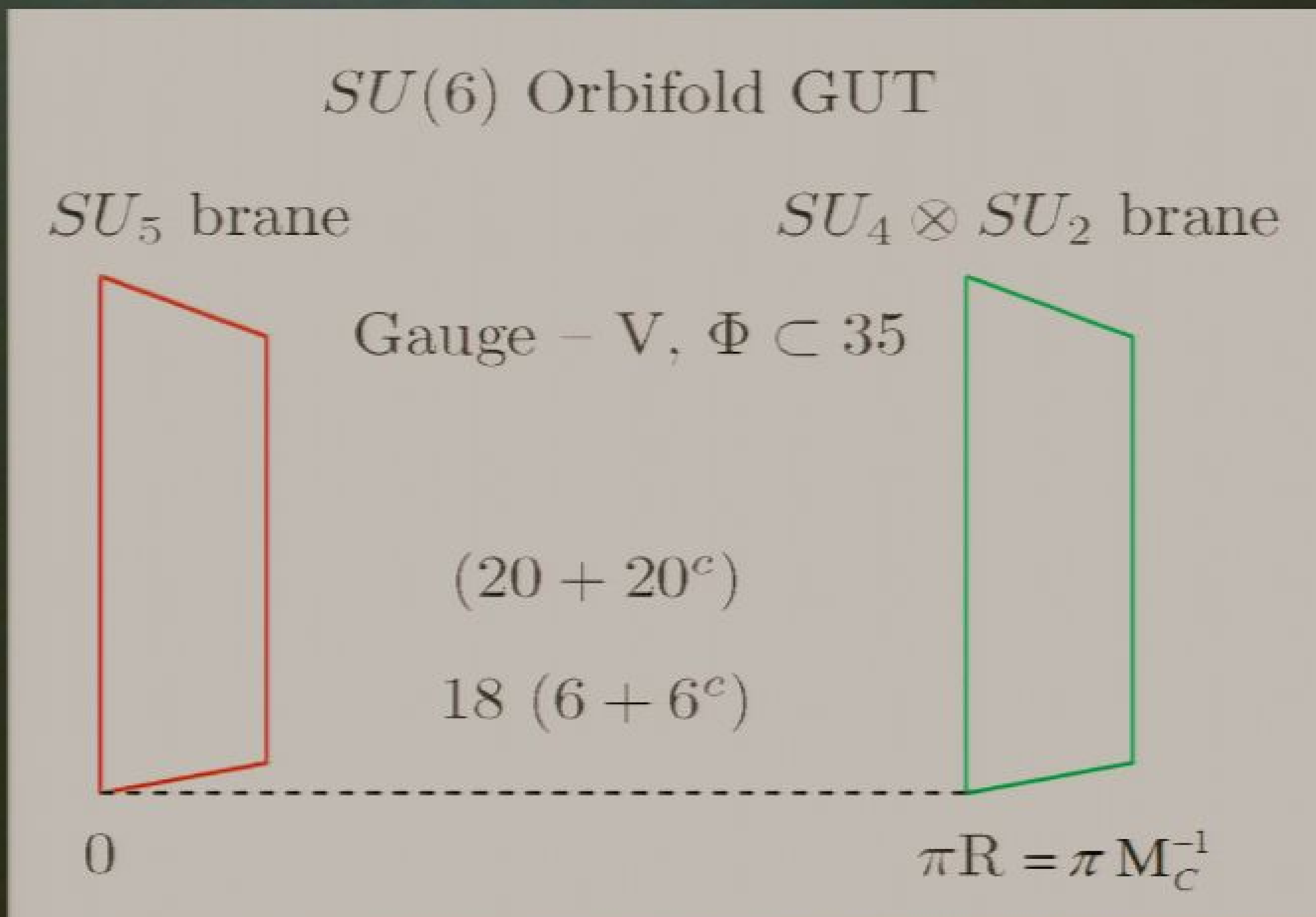
Neutrino masses via See-Saw

Gauge coupling unification



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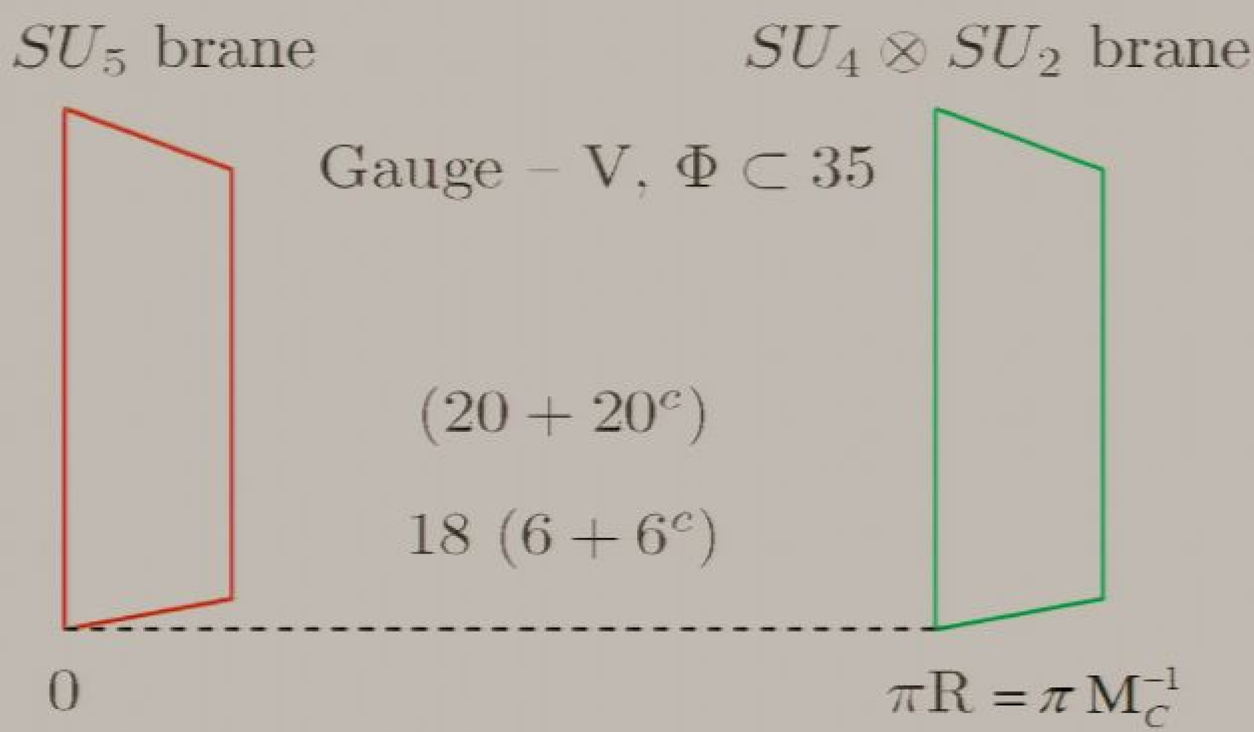

RG equations

$$\alpha_i^{-1}(M_Z) = \alpha_{\mathrm{GUT}}^{-1}\left(M_{string}\right) - \frac{b_i^{MSSM}}{2\pi}\log\frac{M_{string}}{M_Z} + \delta_i^{heavy} + \delta_i^{2loop} + \delta_i^{light}$$

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$\delta_i^{2loop}, \delta_i^{light}$ 2 loop and weak scale corr's

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$\delta_i^{2loop}, \delta_i^{light}$ 2 loop and weak scale corr's

$$\delta_i^{heavy} = \frac{\left(b_i^{++} + b_i^{--}\right)}{4\pi}\log\frac{M_{string}}{M_C} - \frac{b^G}{2\pi}\left(\frac{M_{string}}{M_C} - 1\right)$$

KK modes

RG equations

$$\alpha_i^{-1}(M_Z) = \alpha_{\mathrm{GUT}}^{-1}\left(M_{string}\right) - \frac{b_i^{MSSM}}{2\pi}\log\frac{M_{string}}{M_Z} + \delta_i^{heavy} + \delta_i^{2loop} + \delta_i^{light}$$

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KK modes

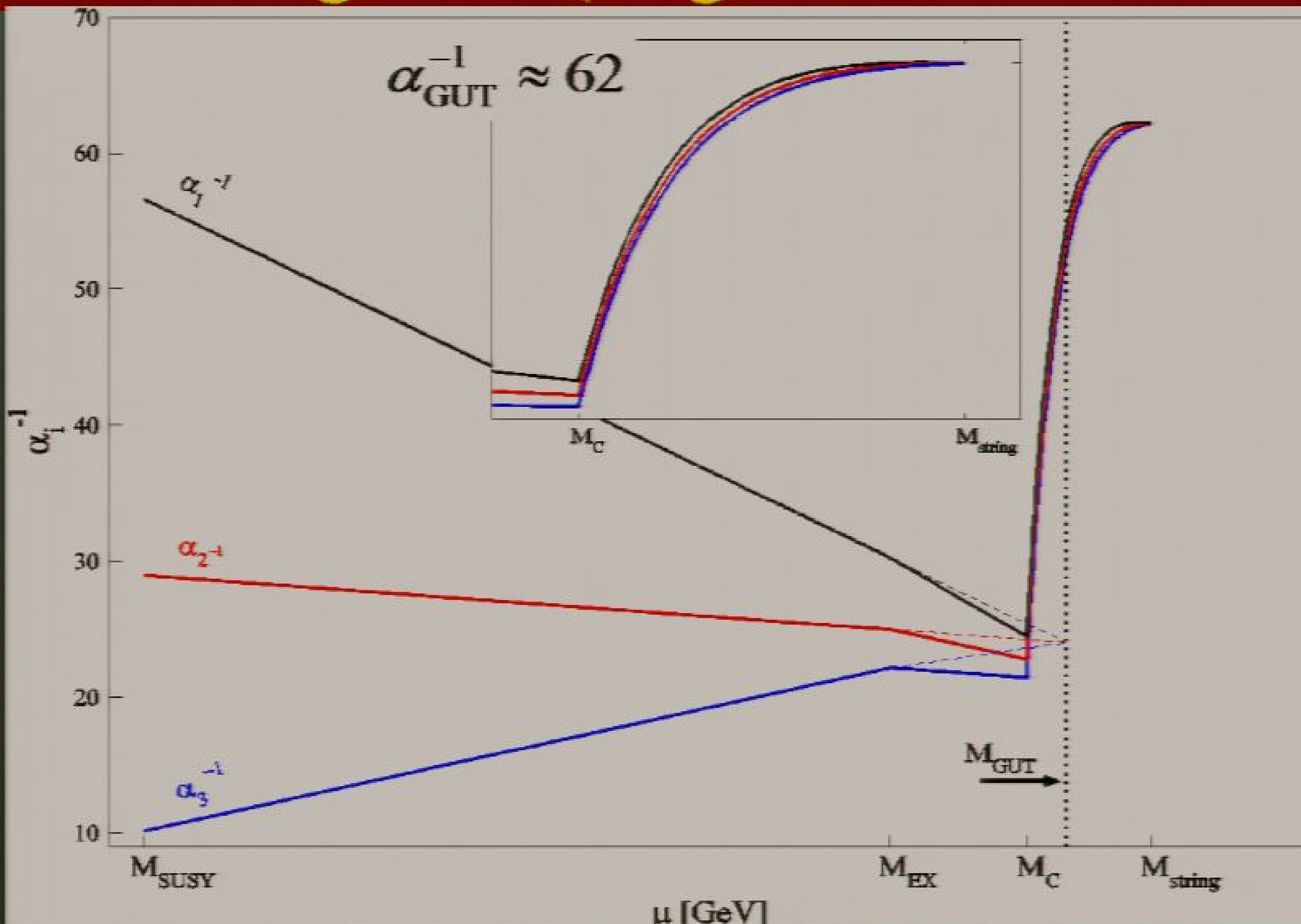
$$-\frac{b_i^{EX}}{2\pi}\log\frac{M_{string}}{M_{EX}}$$

exotics

In this SU(6) orbifold GUT with gauge-Higgs unification the KK modes do NOT focus gauge couplings to unify at M_{string}

Therefore NEED exotics with mass $M_{EX} < M_C$

Gauge coupling unification



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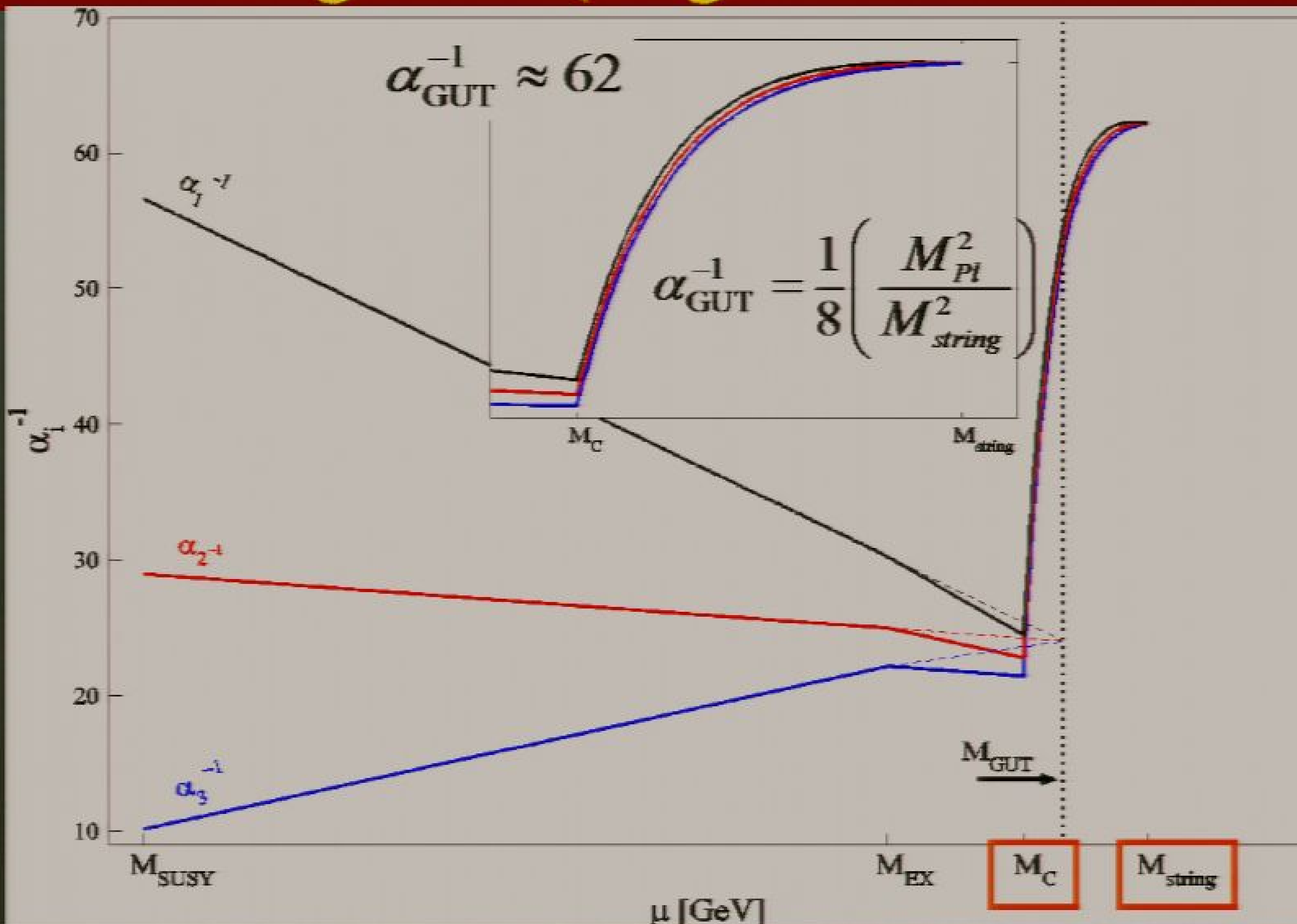

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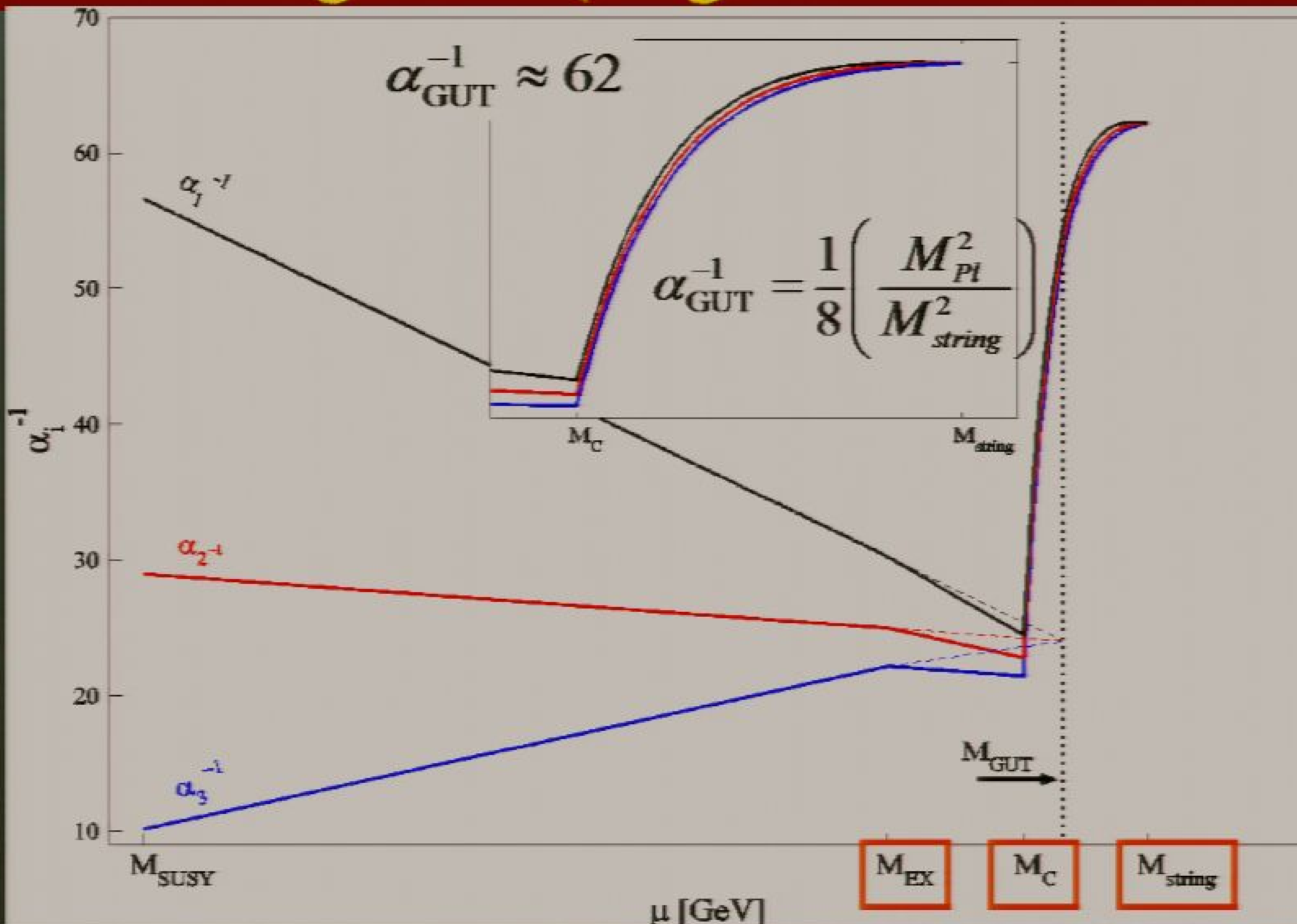
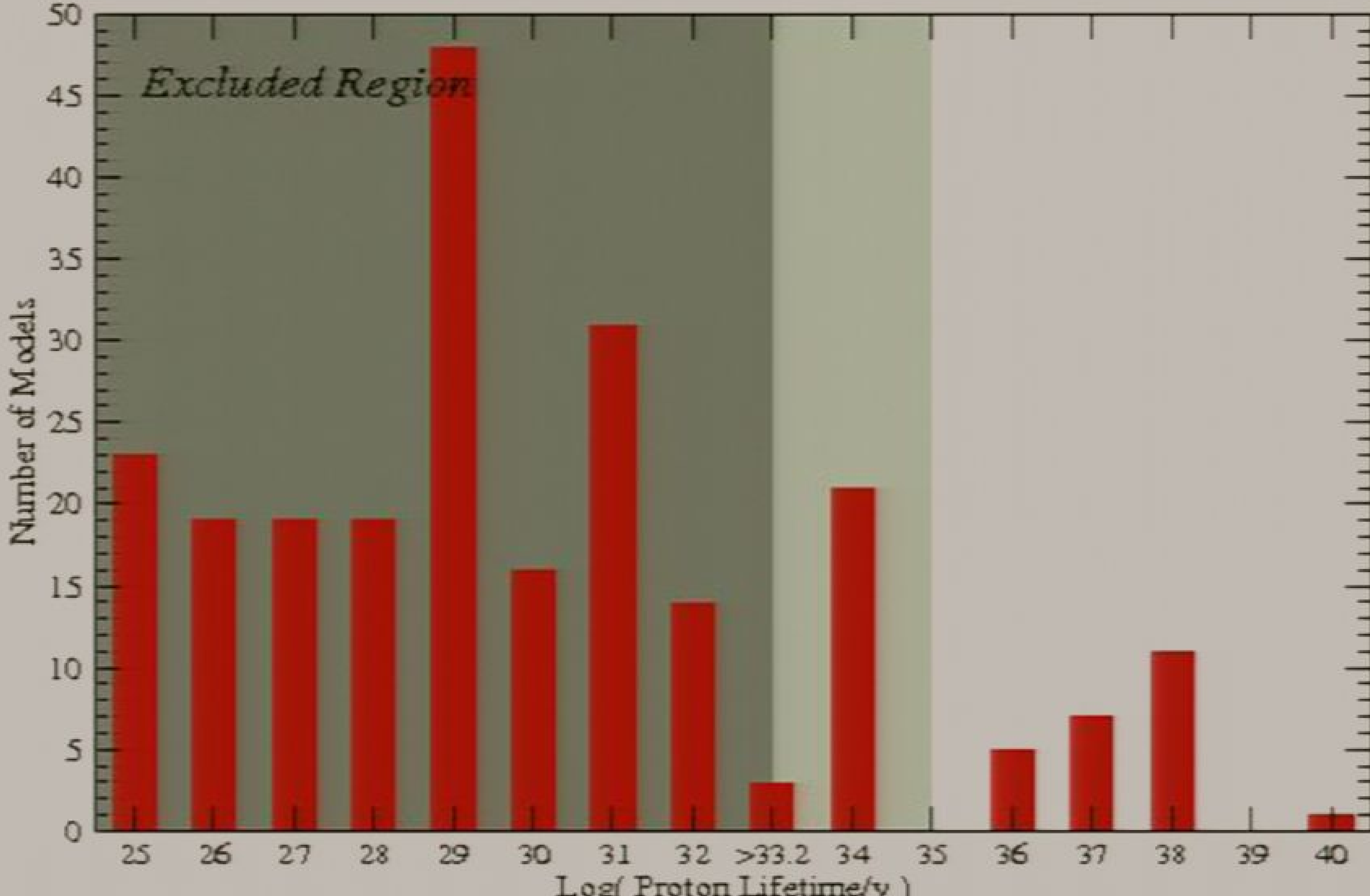


Proton Decay



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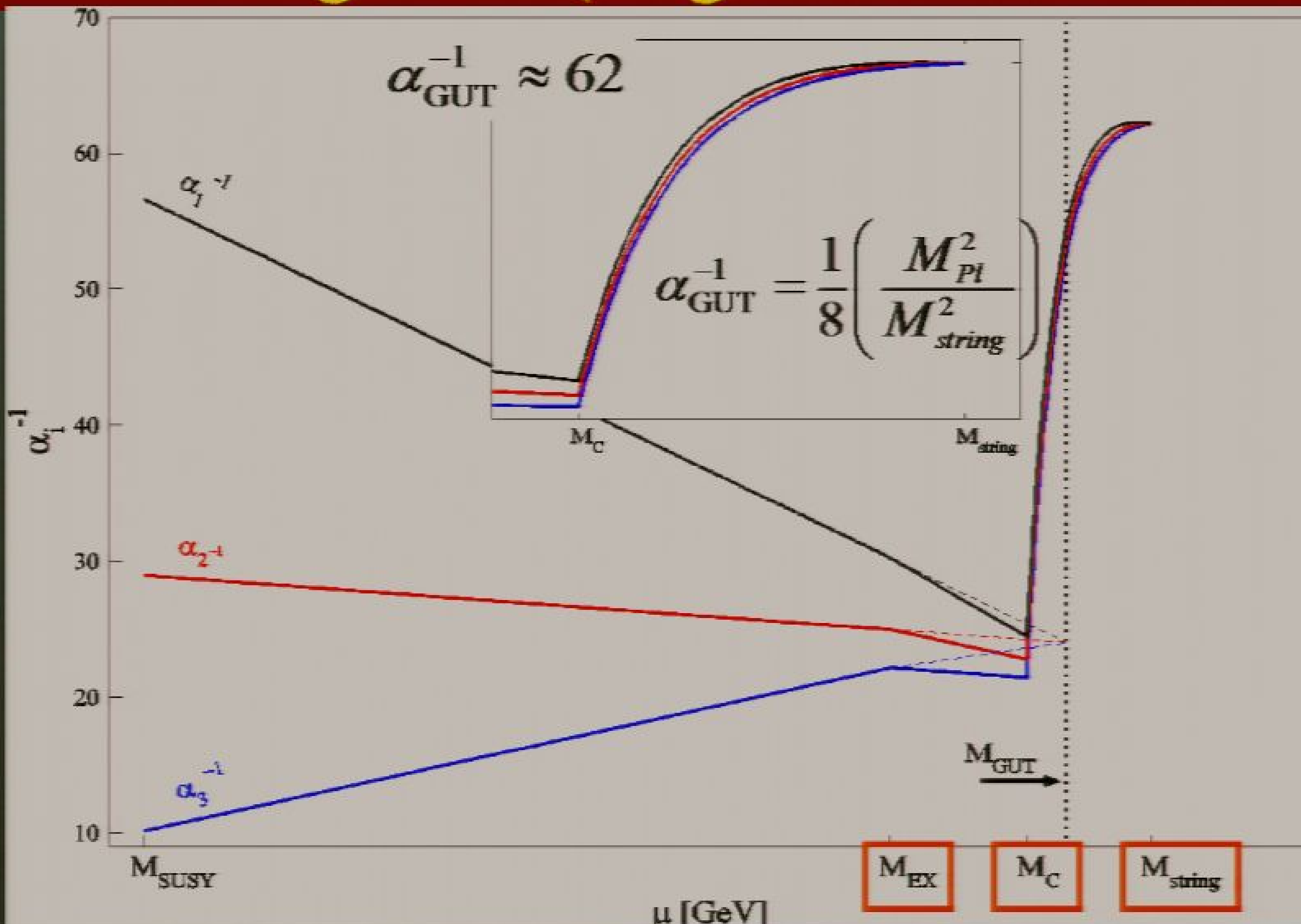

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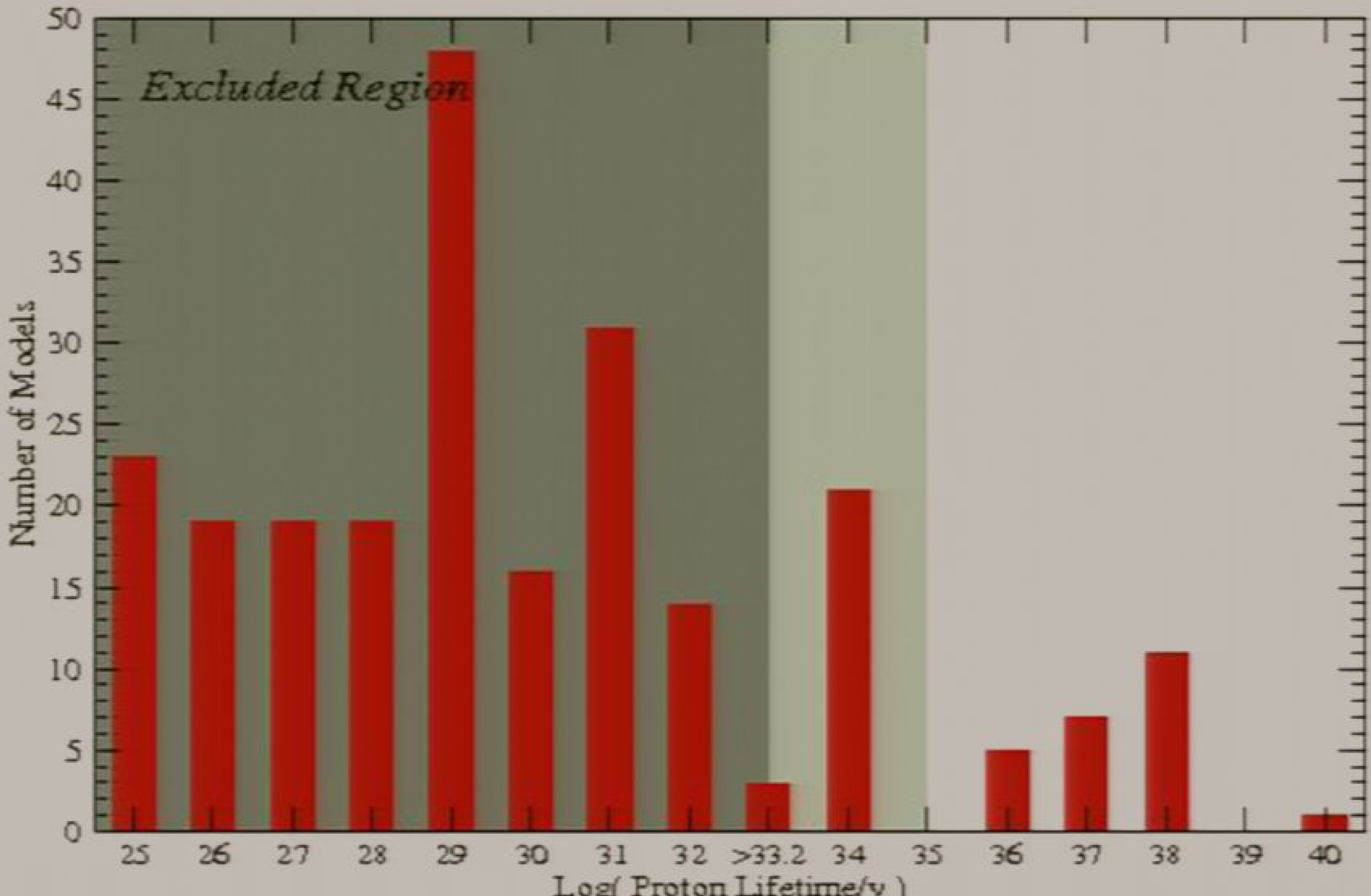

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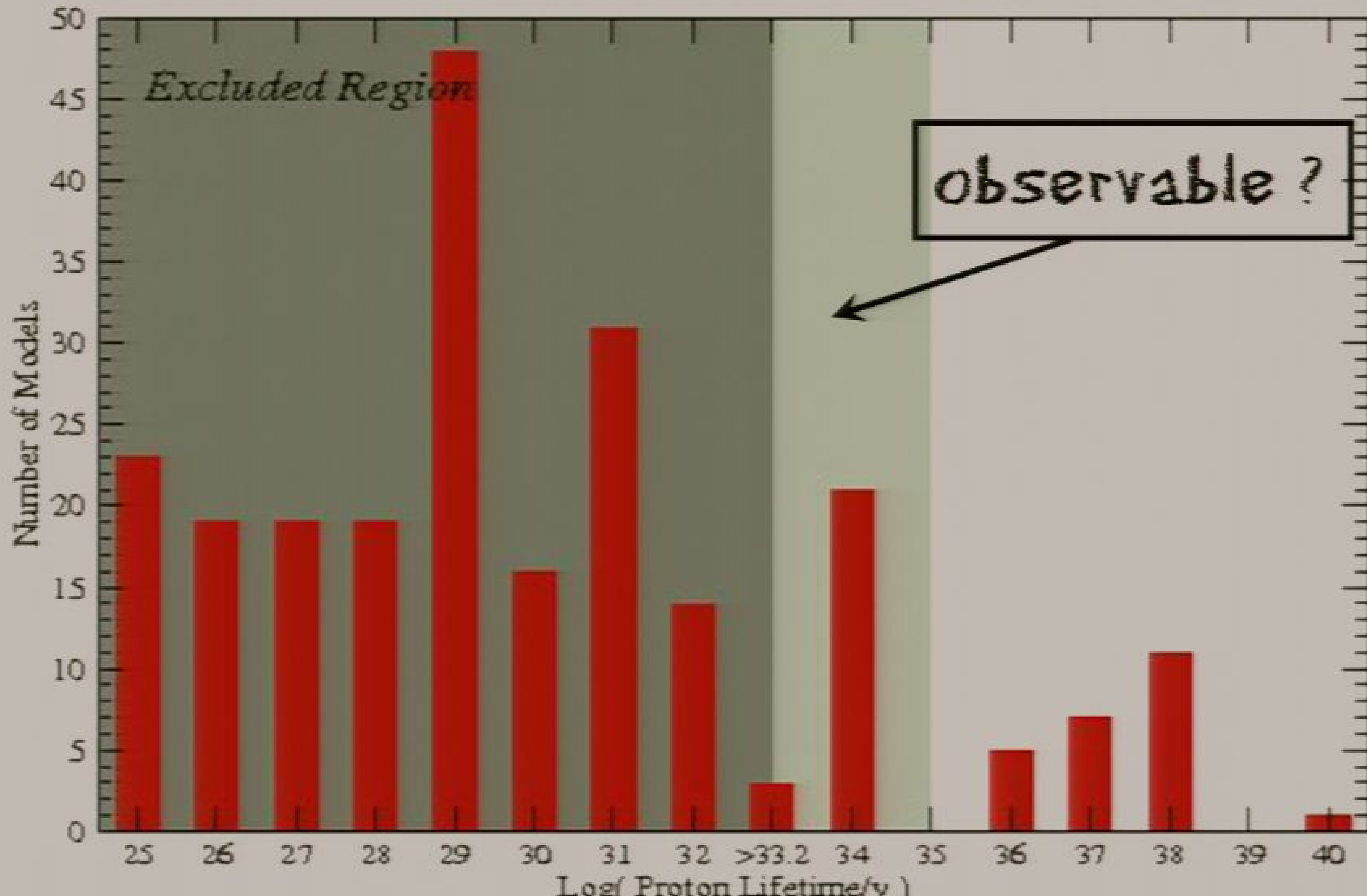
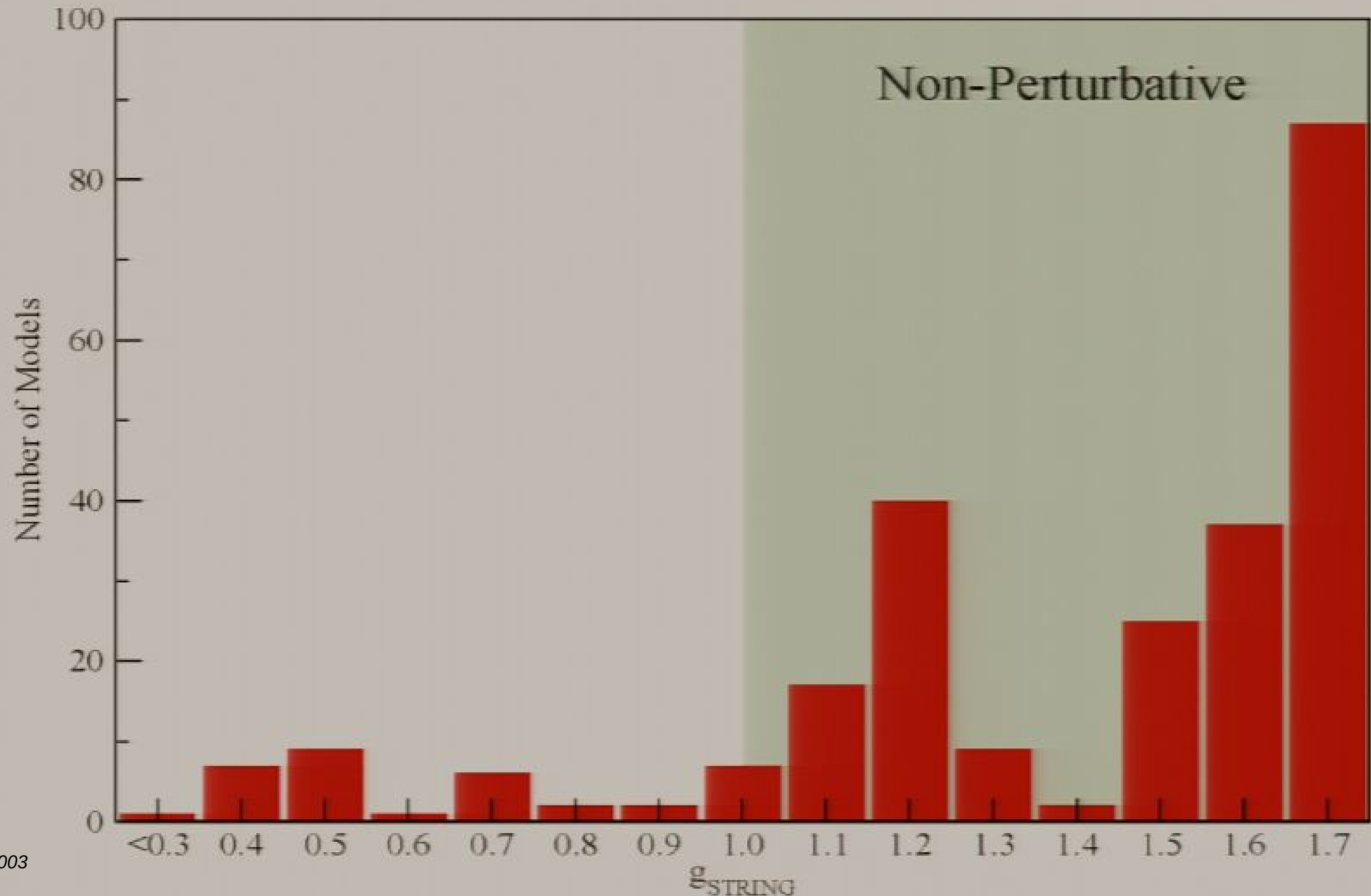


10D string coupling   Dundee & Raby



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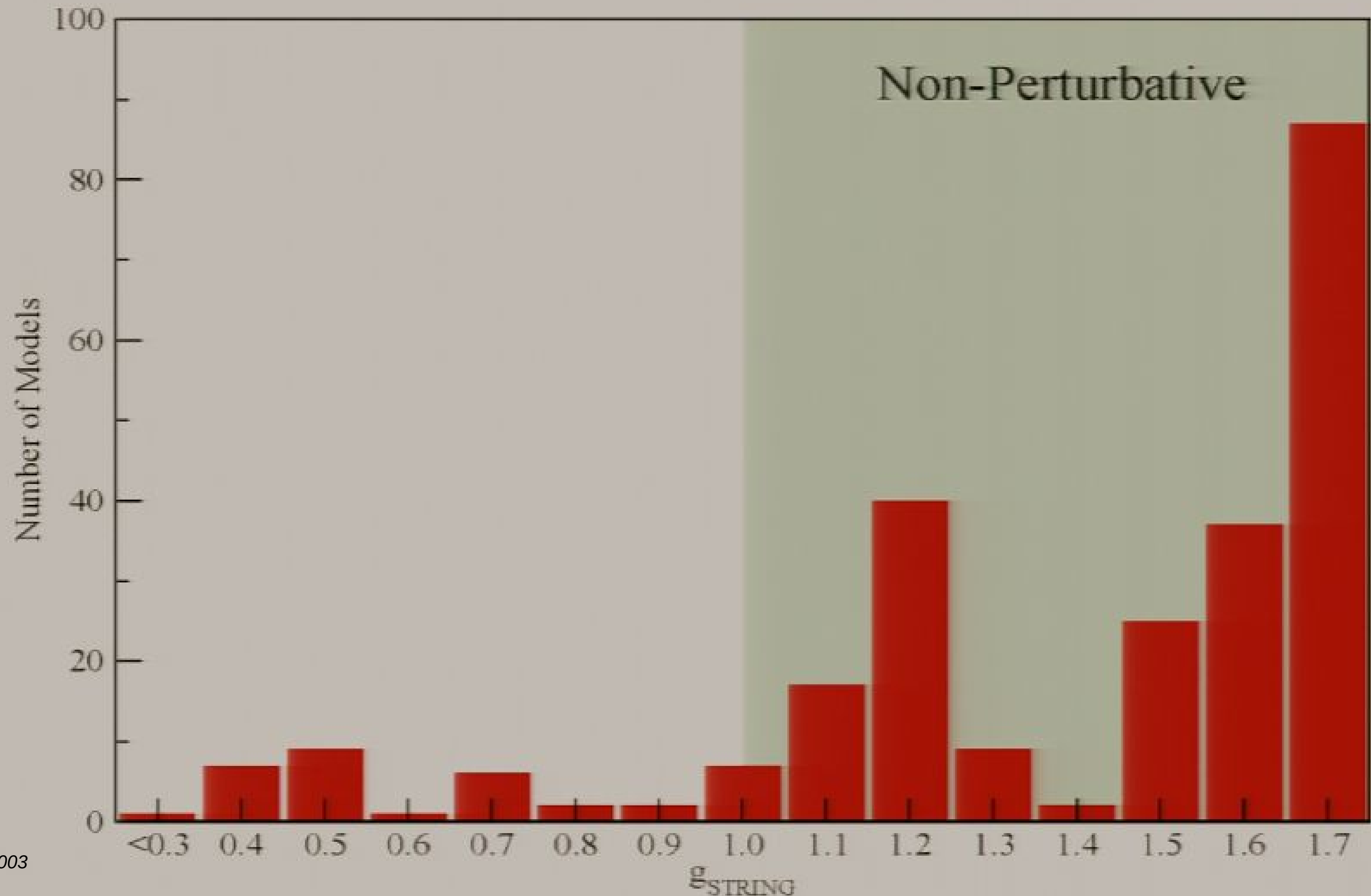

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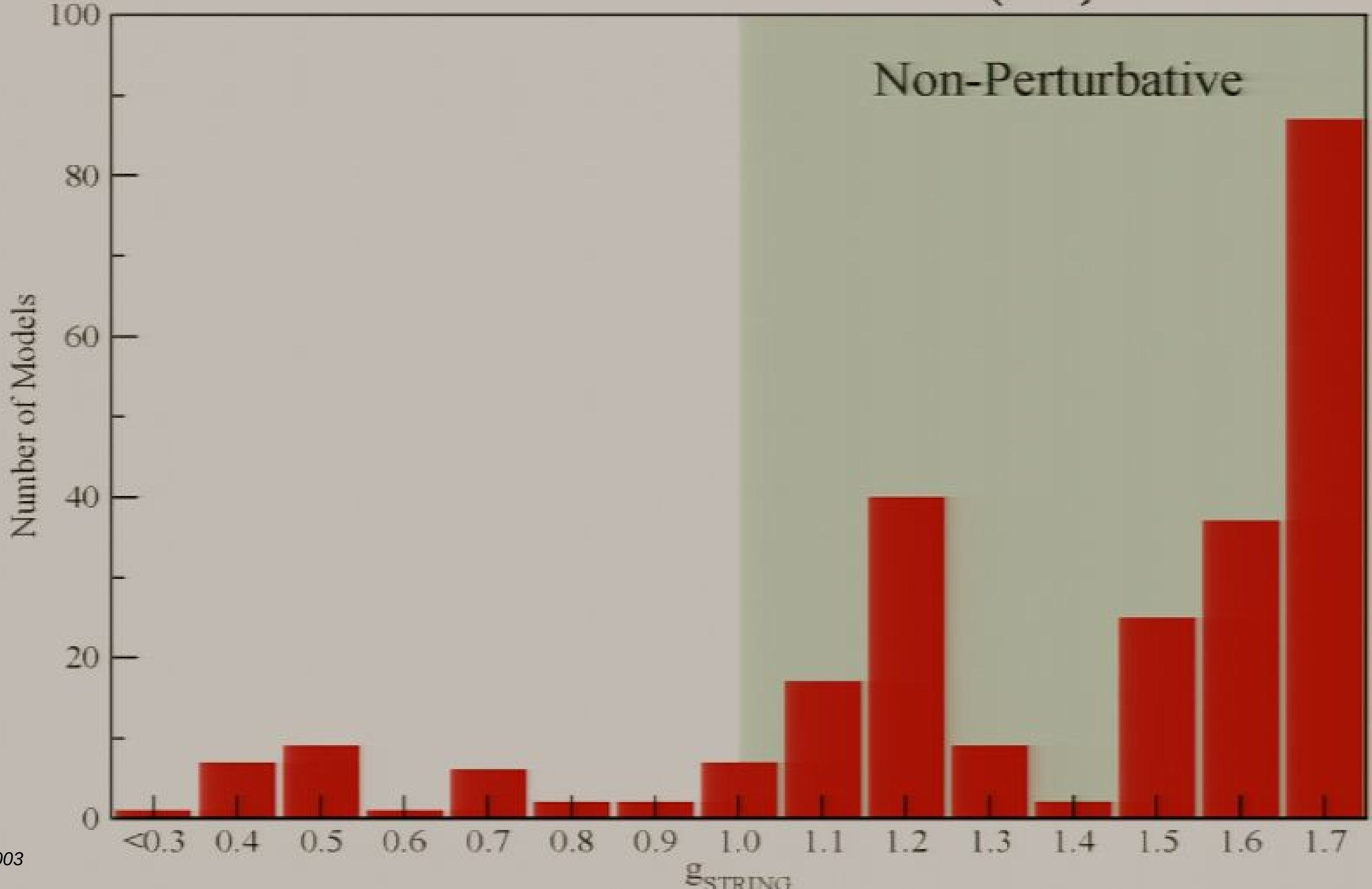

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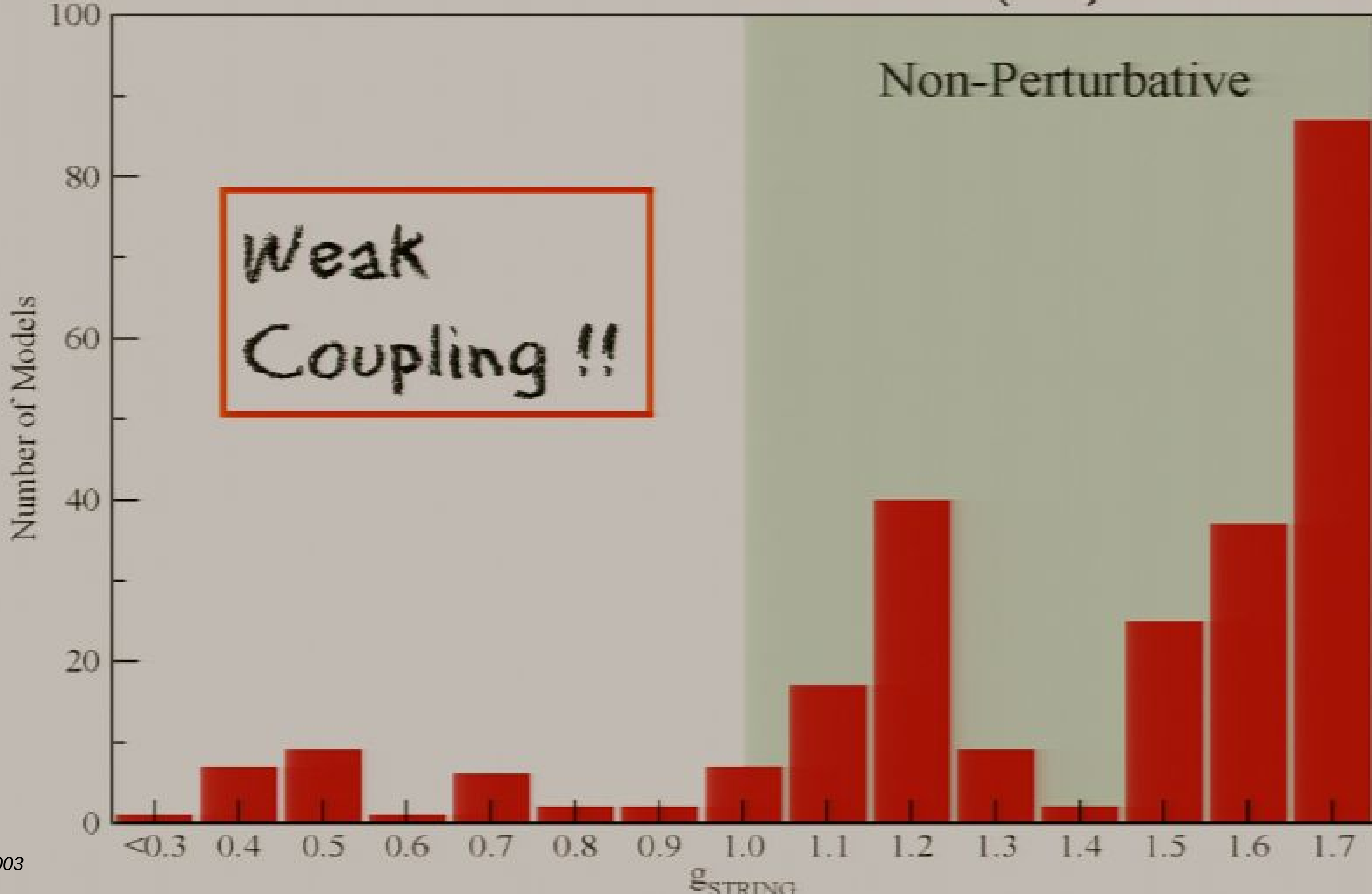

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After first Z_3 orbifold + Wilson line W_3
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$(T_2)^2 / Z_3 \times T_2$

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$$\left(V,\Phi\right) \in 35 \;\Rightarrow\; SU(6) \text{ adjoint}$$
$$\left(20+20^c\right) \oplus 18\left(6+6^c\right)$$

Complete spectrum of 6D SU(6) orbifold GUT

Table 1: The full (five dimensional) spectrum of the models in Lebedev et al. Note that $8_{v+c+s} \equiv 8_v + 8_c + 8_s$. In five dimensions, both Model 1 and Model 2 have the gauge group $SU(6) \times [SO(8) \times SU(3)]'$. Note that states are written in the language of $D = 5, N = 1$.

Multiplet Type	Representation	Number
tensor	singlet	1
vector	$(35, 1, 1) \oplus (1, 28, 1)$	35 + 28
	$\oplus (1, 1, 8) \oplus 5 \times (1, 1, 1)$	8 + 5
hyper	$(20, 1, 1) \oplus (1, 8_{v+c+s}, 1) \oplus 4 \times (1, 1, 1)$	20+24+4
	$\oplus\, 9 \times \{(6, 1, 1) \oplus (\overline{6}, 1, 1)\}$	108
	$\oplus\, 9 \times \{(1, 1, 3) \oplus (1, 1, \overline{3})\}$	54
	$\oplus\, 3 \times (1, 8_{v+c+s}, 1)$	72
	$\oplus\, 36 \times (1, 1, 1)$	36
	SUGRA singlets	2

40

Complete spectrum of 6D SU(6) orbifold GUT

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Satisfies Gravity anomaly constraint

$$N_H - N_V^6 + 29\, N_T = 273$$

$$320 - 76 + 29(1) = 273$$

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F-theory CY_3 (T_2 fibration over F_n) x T_2 dual to

$E_8 \times E_8$ heterotic $K_3 \times T_2$ w/instantons

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E_8 (12 instanton

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Bershadsky, Intriligator, Kachru, Morrison, Sadov & Vafa

Type	Group	Matter content	Dim($\mathcal{M}$)
E_7	E_7	$(\frac{n}{2}+4)\mathbf{56}$	$2n+21$
E_6^s	E_6	$(n+6)\mathbf{27}$	$3n+28$
E_6^{ns}	F_4	$(n+5)\mathbf{26}$	$4n+34$
D_5^s	$SO(10)$	$(n+4)\mathbf{16}+(n+6)\mathbf{10}$	$4n+33$
D_5^{ns}	$SO(9)$	$(n+5)\mathbf{9}+(n+4)\mathbf{16}$	$5n+39$
D_4^s	$SO(8)$	$(n+4)(\mathbf{8}_c+\mathbf{8}_s+\mathbf{8}_v)$	$6n+44$
D_4^{ss}	$SO(7)$	$(n+3)\mathbf{7}+(2n+8)\mathbf{8}$	$7n+48$
D_4^{ns}	G_2	$(3n+10)\mathbf{7}$	$9n+56$
A_3^s	$SU(4)$	$(n+2)\mathbf{6}+(4n+16)\mathbf{4}$	$8n+51$
A_3^{ns}	$SO(5)$	$(n+1)\mathbf{5}+(4n+16)\mathbf{4}$	$9n+53$
$A_1\times A_1$	$SO(4)$	$n(\mathbf{2},\mathbf{2})+(4n+16)[(\mathbf{1},\mathbf{2})+(\mathbf{2},\mathbf{1})]$	$10n+54$
A_2^s	$SU(3)$	$(6n+18)\mathbf{3}$	$12n+66$
A_1	$SU(2)$	$(6n+16)\mathbf{2}$	$18n+83$
A_1	$SU(2)_2$	$(8n+32)\mathbf{2}+(n-1)\mathbf{3}$	$11n+54$
D_6^s	$SO(12)$	$\frac{r}{2}\mathbf{32}+(\frac{4+n-r}{2})\mathbf{32'}+(n+8)\mathbf{12}$	$2n+18$
D_6^{ns}	$SO(11)$	$(\frac{n}{2}+2)\mathbf{32}+(n+7)\mathbf{11}$	$3n+26$
A_5^s	$SU(6)$	$\frac{r}{2}\mathbf{20}+(16+r+2n)\mathbf{6}+(2+n-r)\mathbf{15}$	$3n-r+21$
A_5^{ns}	$Sp(3)$	$(16+2n+\frac{3}{2}r)\mathbf{6}+(n+1-r)\mathbf{14}+\frac{1}{2}r\mathbf{14'}$	$4n+23-2r$
A_4^s	$SU(5)$	$(3n+16)\mathbf{5}+(2+n)\mathbf{10}$	$5n+36$
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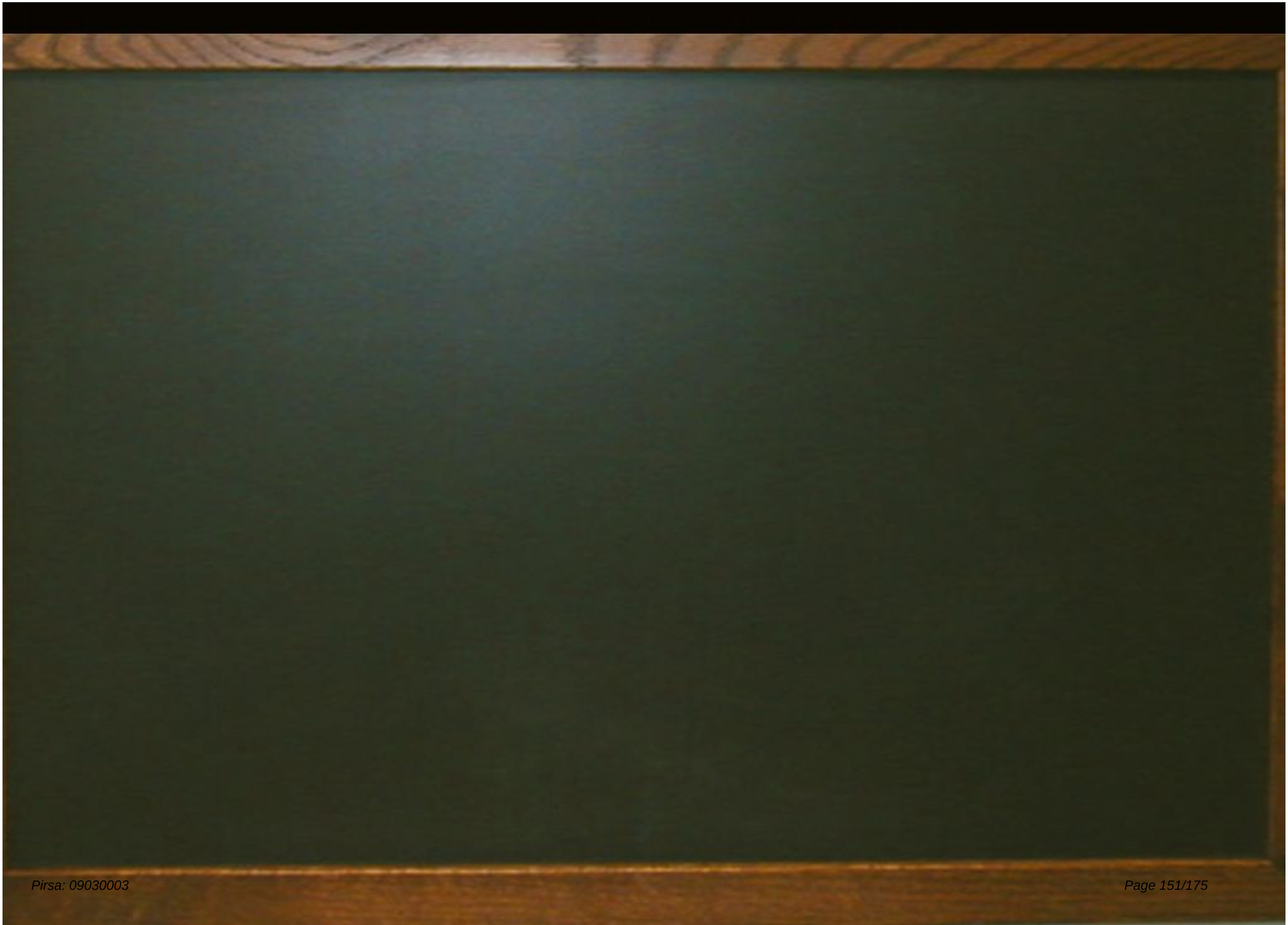

Derivable f

Derivable from a dual F the

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Work in progress

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- Find more general description i.e. all models in the same universality class
- Provide a general understanding of moduli space

Derivable from a dual F theory construction ??

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w/ Bobkov, Weigand & Westphal

- Find more general description i.e. all models in the same universality class
- Provide a general understanding of moduli space
- Help understand moduli stabilization & SUSY breaking ?

Conclusions

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w/ Caveat

SUSY breaking and lifting flat directions ??

Orbifold & Local GUT ⟶ MSSM

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