Asymptotic UV-safe Unification of Gauge and Yukawa Couplings: An exceptional case

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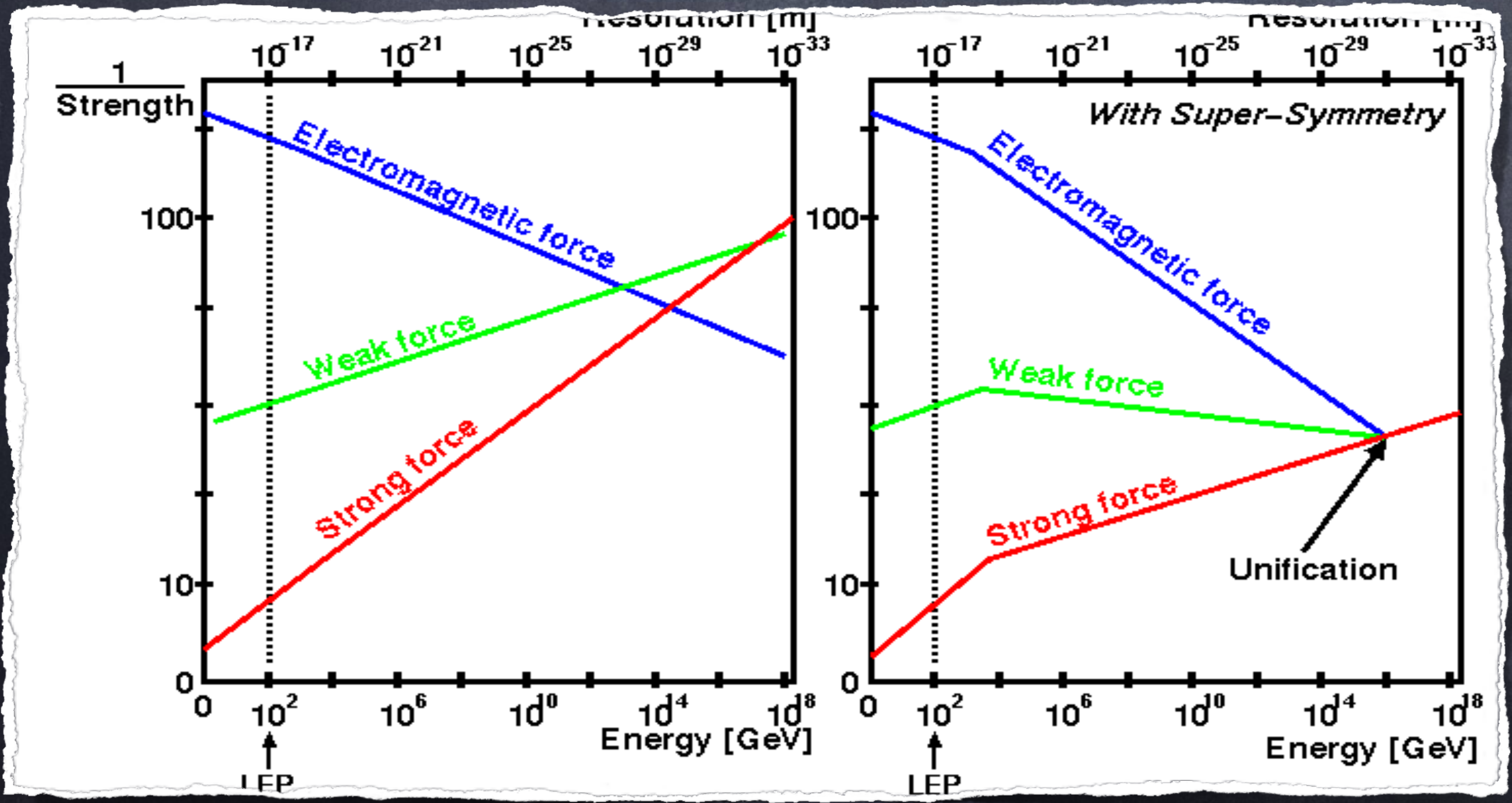
with A. Deandrea, R. Pasechnik, Z.W. Wang 2302.11671
(also w. A.Cornell, A.Deandrea, C.Cot in 2012.14732)

Traditional GUTs

- SM gauge couplings expected to be equal at the GUT scale
- supersymmetry helps building "realistic" models
- proton decay inevitable!



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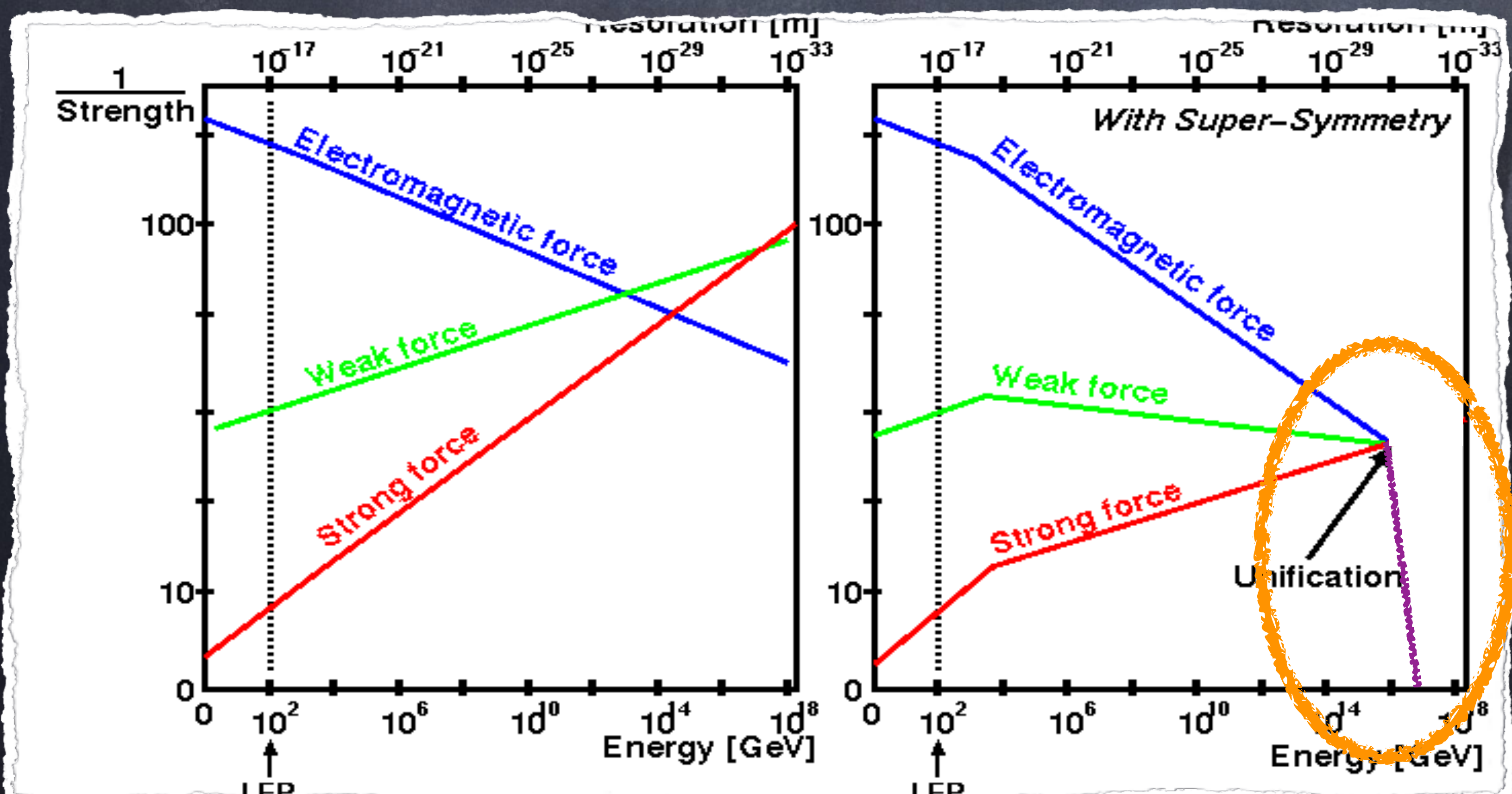
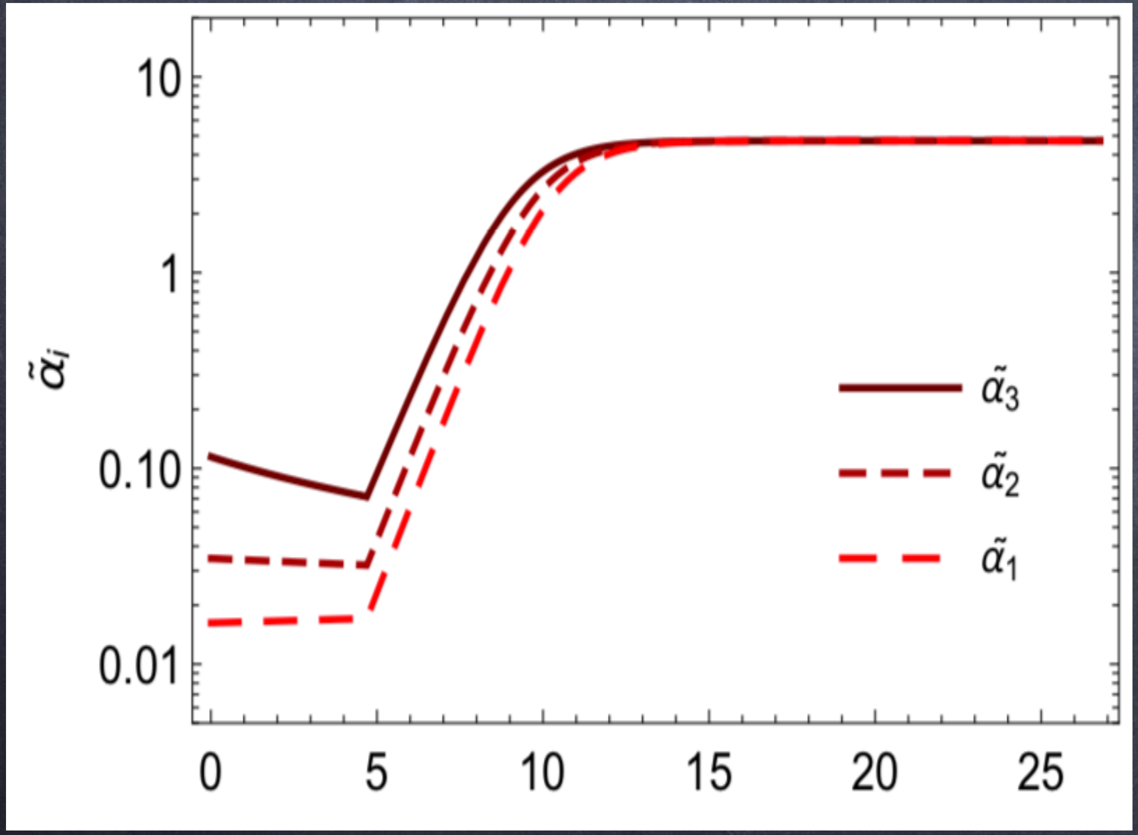


However:

- Large matter representations needed to break the gauge symmetry!
- Landau pole!!!!

asymptotic GUT (aGUT)

- Gauge couplings are never equal, but tend to the same UV fixed point!



A) Realised in asympt. safe theories (via large Nf resum)

(Intermediate Pati-Salam unification needed)

Molinaro et al, PRD 98 (2018) 11

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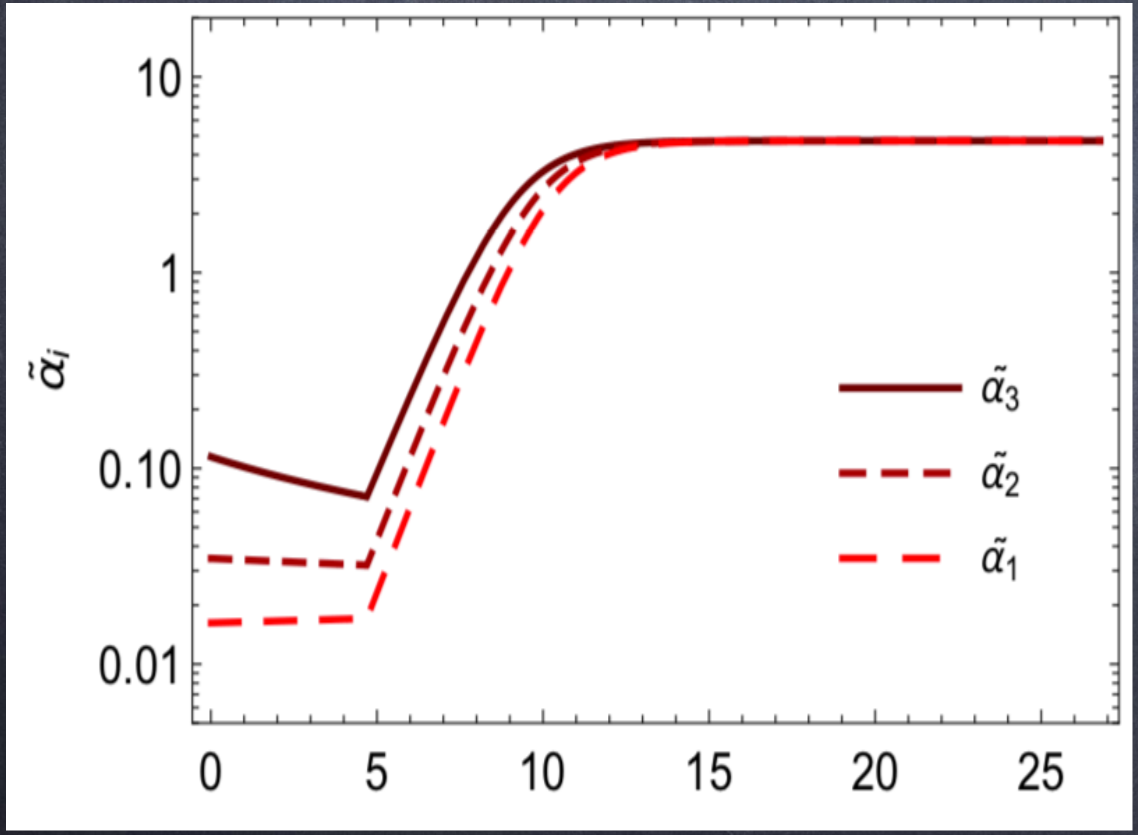


B) Extra compact dimensions

$$2\pi \frac{d\alpha}{d\ln\mu} = \mu R\, b_5\, \alpha^2$$

$\tilde{\alpha} = \mu R\, \alpha$ ('t Hooft coupling in 5D)

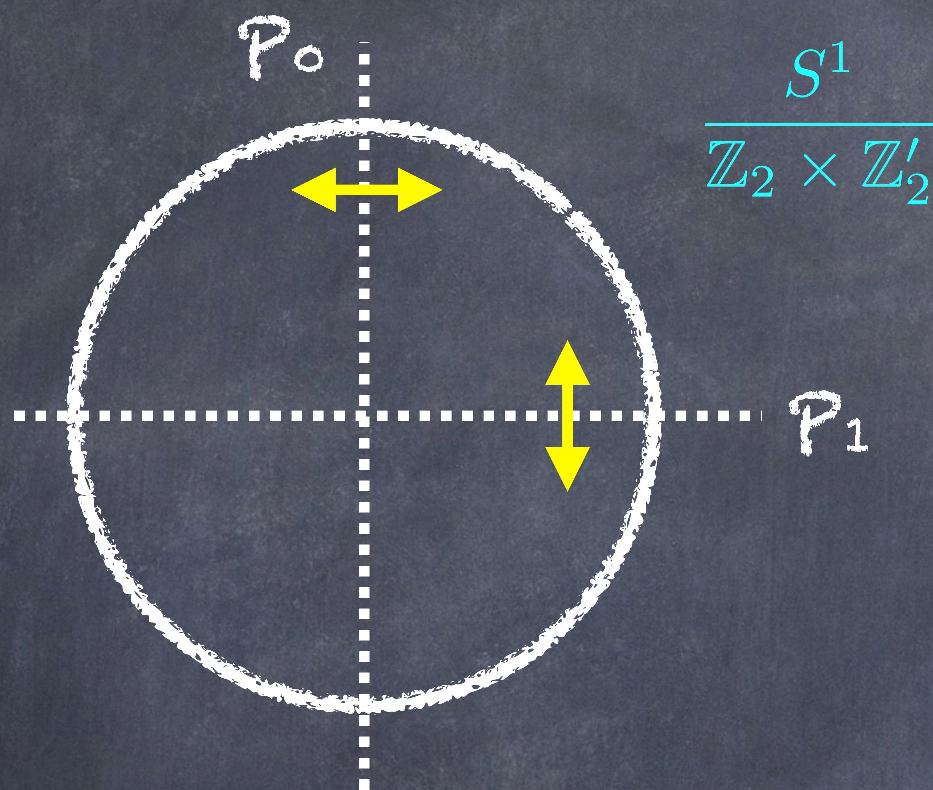
$$2\pi \left(\tilde{\alpha} + \frac{d\tilde{\alpha}}{d\ln\mu} \right) = b_5\, \tilde{\alpha}^2$$

$$\tilde{\alpha}_{UV} = -\frac{2\pi}{b_5}$$

Gies, PRD 68 (2003)
Morris, JHEP 01 (2005) 002

Minimal SU(5) aGUT

Cacciapaglia et al, PRD 104 (2021) 7



$$(P_0) \Rightarrow \begin{cases} A^a_\mu(x,-y) = P_0 A^a_\mu(x,y) P_0^\dagger\,, \\ A^a_y(x,-y) = -P_0 A^a_y(x,y) P_0^\dagger\,, \end{cases}$$

$$(P_1) \Rightarrow \begin{cases} A^a_\mu(x,\pi R - y) = P_1 A^a_\mu(x,y) P_1^\dagger\,, \\ A^a_y(x,\pi R - y) = -P_1 A^a_y(x,y) P_1^\dagger\,, \end{cases}$$

$$P_0 = (+ + + - -)\,, \qquad P_1 = (+ + + + +)\,.$$

$$\psi_5 = \begin{pmatrix} B^c \\ l \end{pmatrix} \quad \begin{matrix} (- +) \\ (+ +) \end{matrix}$$ Lh zero

$$\psi_5 = \begin{pmatrix} b \\ L^c \end{pmatrix} \quad \begin{matrix} (- -) \\ (+ -) \end{matrix}$$ Rh zero

- SU(5) broken in y=0 to the SM by boundary conditions
- SM fermions cannot be embedded in complete multiplets of SU(5)!!!

Yukawa non-unification

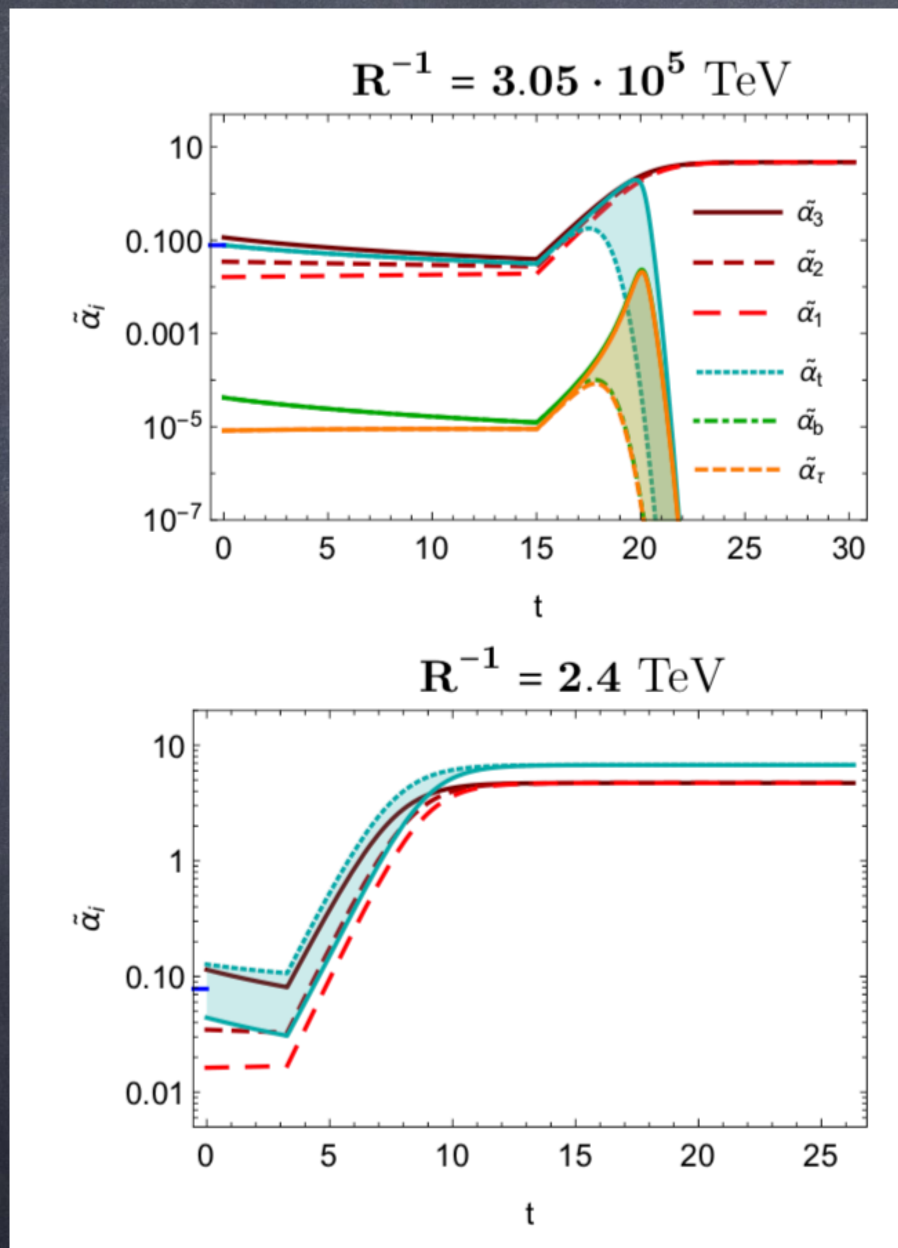
The most general bulk Lagrangian reads:

$$\mathcal{L}_{SU(5)} = -\frac{1}{4}F^{(a)}_{MN}F^{(a)MN} - \frac{1}{2\xi}(\partial_\mu A^\mu - \xi\partial_5 A_y)^2 + i\overline{\psi_5}\not{D}\psi_5 + i\overline{\psi_{\overline{5}}}\not{D}\psi_{\overline{5}} + i\overline{\psi_{10}}\not{D}\psi_{10}$$
$$+ i\overline{\psi_{\overline{10}}}\not{D}\psi_{\overline{10}} - \left(\sqrt{2}Y_\tau\,\overline{\psi_{\overline{5}}}\psi_{\overline{10}}\phi_5^* + \sqrt{2}Y_b\,\overline{\psi_5}\psi_{10}\phi_5^* + \frac{1}{2}Y_t\,\epsilon_5\,\overline{\psi_{\overline{10}}}\psi_{10}\phi_5 + \text{h.c.}\right)$$
$$+ |D_M\phi_5|^2 - V(\phi_5) + i\overline{\psi_1}\not{\partial}\psi_1 - \left(Y_\nu\,\overline{\psi_1}\psi_{\overline{5}}\phi_5 + \text{h.c.}\right),$$

- Yukawas DO NOT unify!
- Baryon and lepton numbers can be defined (no proton decay processes)

The Yukawa sector runs into problems

Bulk Yukawas



For smaller values of the KK scale the Yukawas run to Landau poles

Localising all Yukawas except the top, allows for UV fixed point.

But hard to do: SO(10) is ruled out, in fact!

Khojali et al, 2210.03596

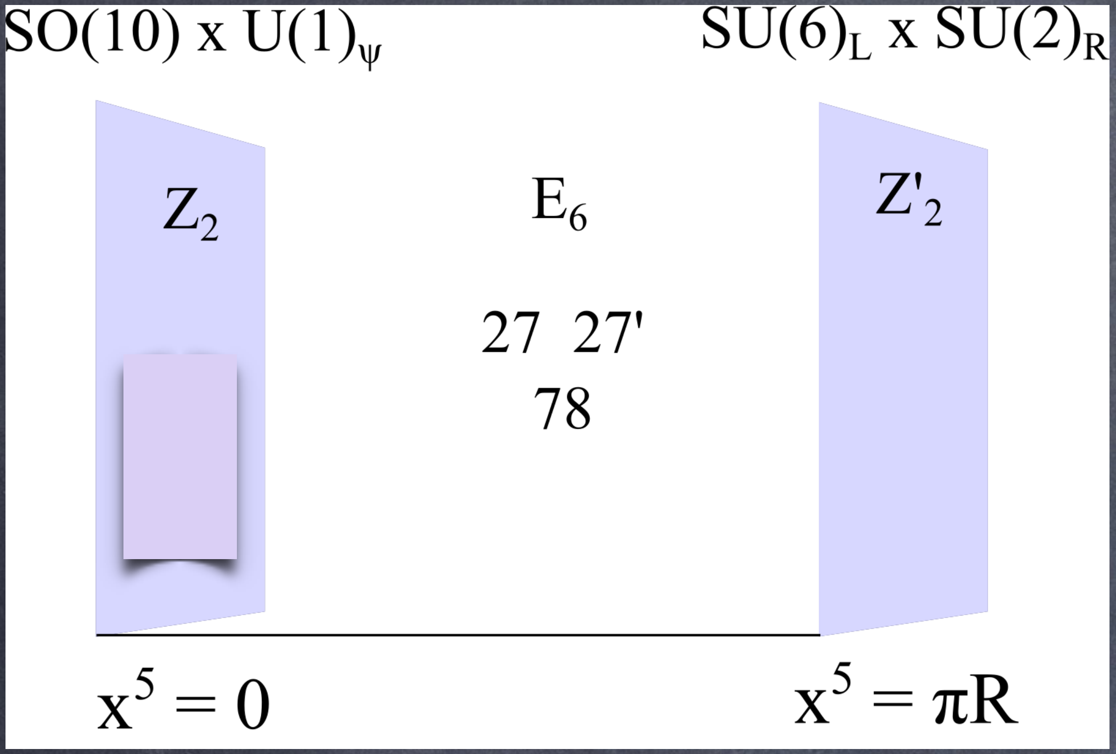
Supersymmetry to the rescue

- Supersymmetry allows to generate fermions as gauge fields (gauginos)
- In E6, the adjoint 78 contains the right states (but in vector-like pairs)

See Kobayashi, Raby, Zhang, Nucl. Phys. B704, 3 (2005)

The exceptional case

Cacciapaglia et al, 2302.11671



4D gauge symmetry:

$$SU(4) \times SU(2)_L \times SU(2)_R \times U(1)_\psi$$

Bulk interactions limited To (SUSY) gauge!

- Right-handed SM fermions from the adjoint (gauginos)
- Left-handed and Higgs(es) from the 27
- 27' to give mass to unwanted states

The exceptional case

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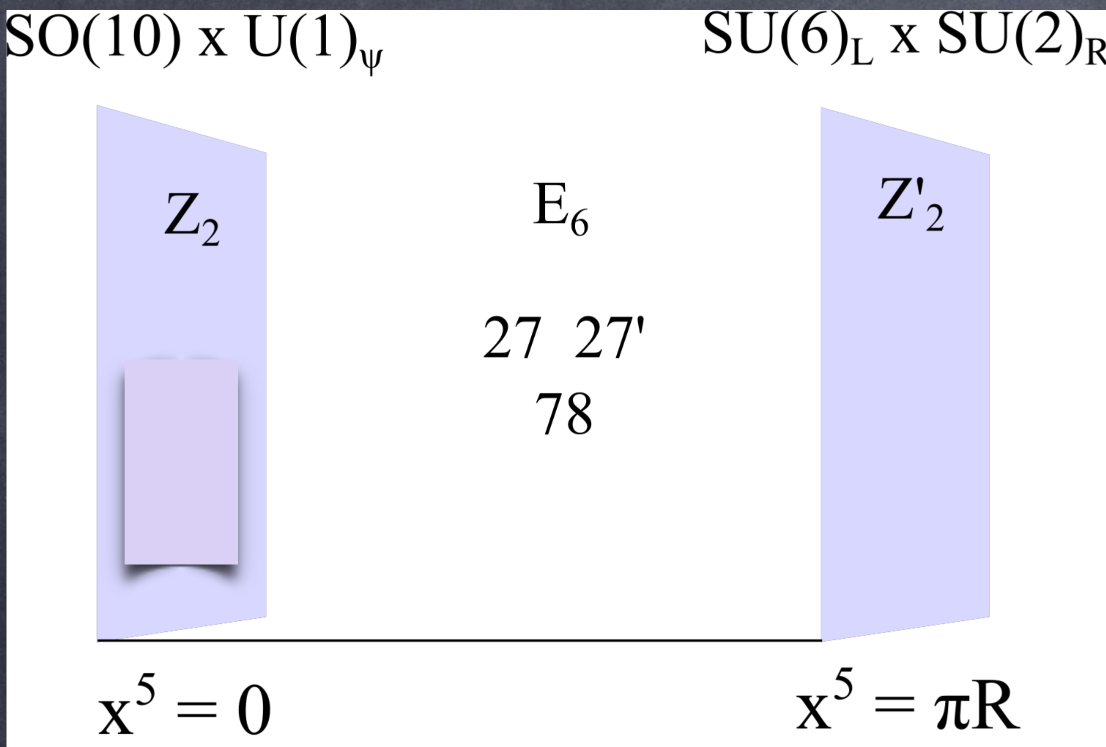

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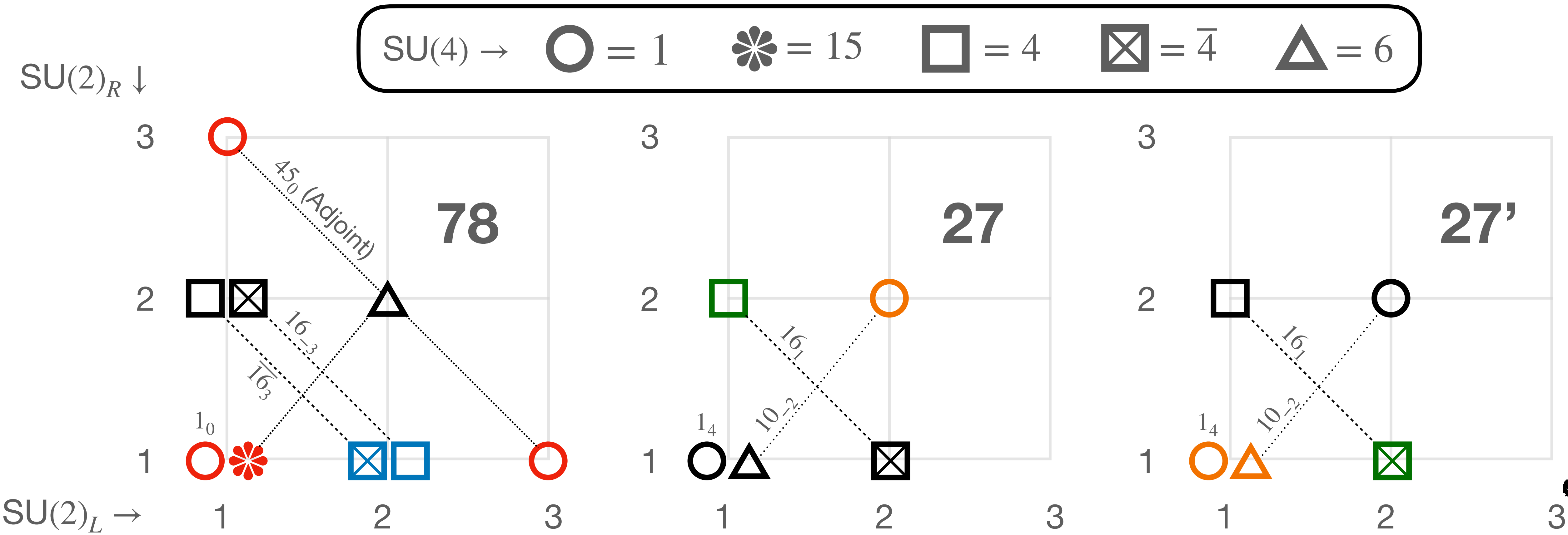

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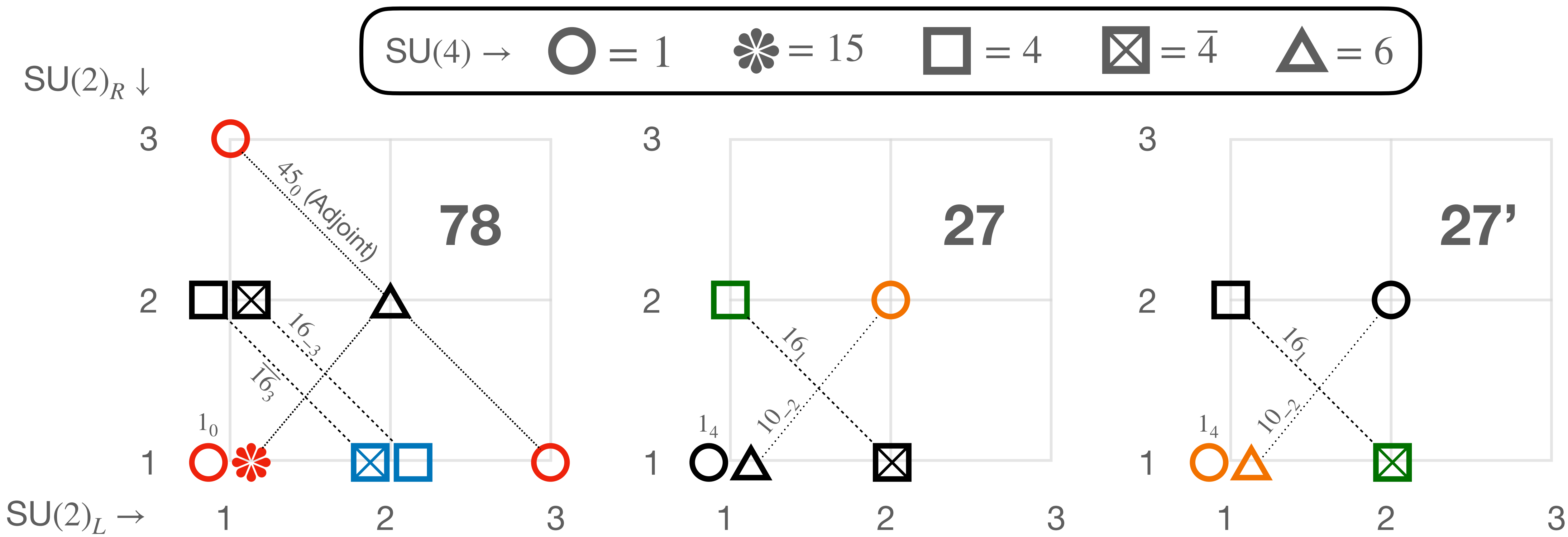


$$g\ \Phi^c_{27}\Phi_{78}\Phi_{27} \supset \frac{g}{\sqrt{2}}(\mathbf{1},\mathbf{2},\mathbf{2})_2\ (\bar{\mathbf{4}},\mathbf{1},\mathbf{2})_{-3}\ (\mathbf{4},\mathbf{2},\mathbf{1})_1$$

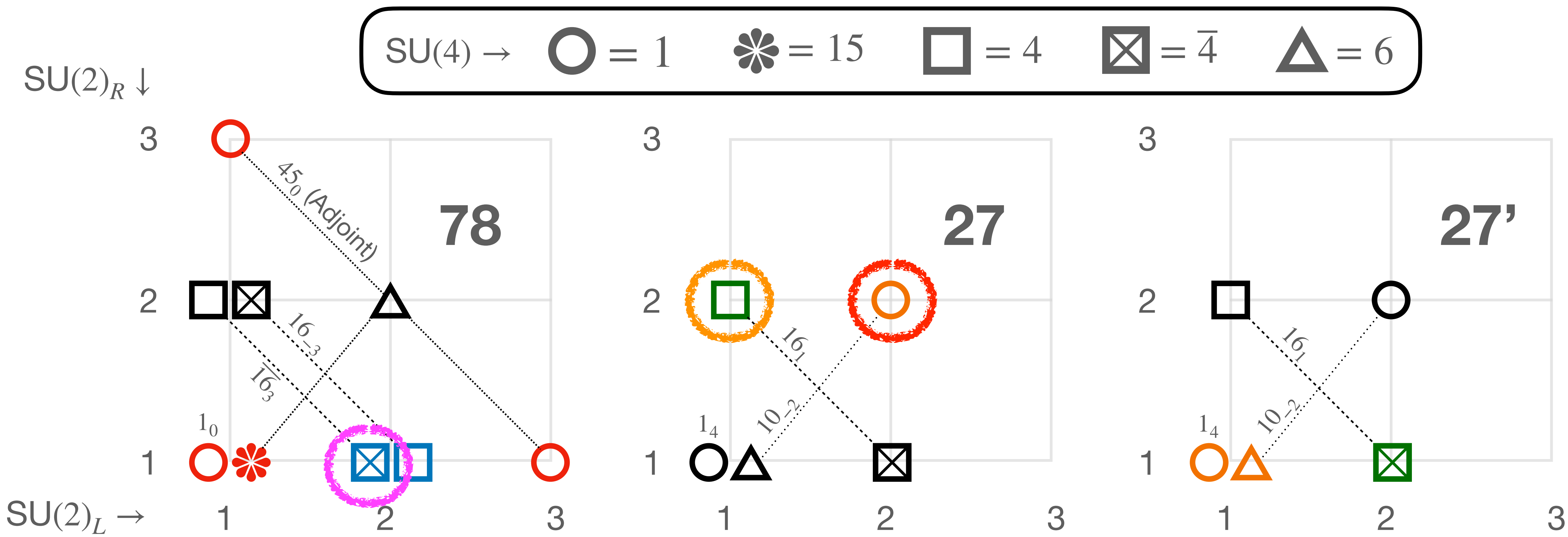
-> SM Yukawa couplings!

$$g\ \Phi^c_{27'}\Phi_{78}\Phi_{27'} \supset -\frac{g}{\sqrt{2}}(\mathbf{1},\mathbf{1},\mathbf{1})_{-4}\ (\mathbf{4},\mathbf{1},\mathbf{2})_3\ (\bar{\mathbf{4}},\mathbf{1},\mathbf{2})_1 + \frac{g}{\sqrt{2}}(\mathbf{6},\mathbf{1},\mathbf{1})_2\ (\bar{\mathbf{4}},\mathbf{1},\mathbf{2})_{-3}\ (\bar{\mathbf{4}},\mathbf{1},\mathbf{2})_1$$

-> Gives mass to unwanted Chiral states via U(1) breaking

Bulk interactions preserve Baryon number!

The exceptional case



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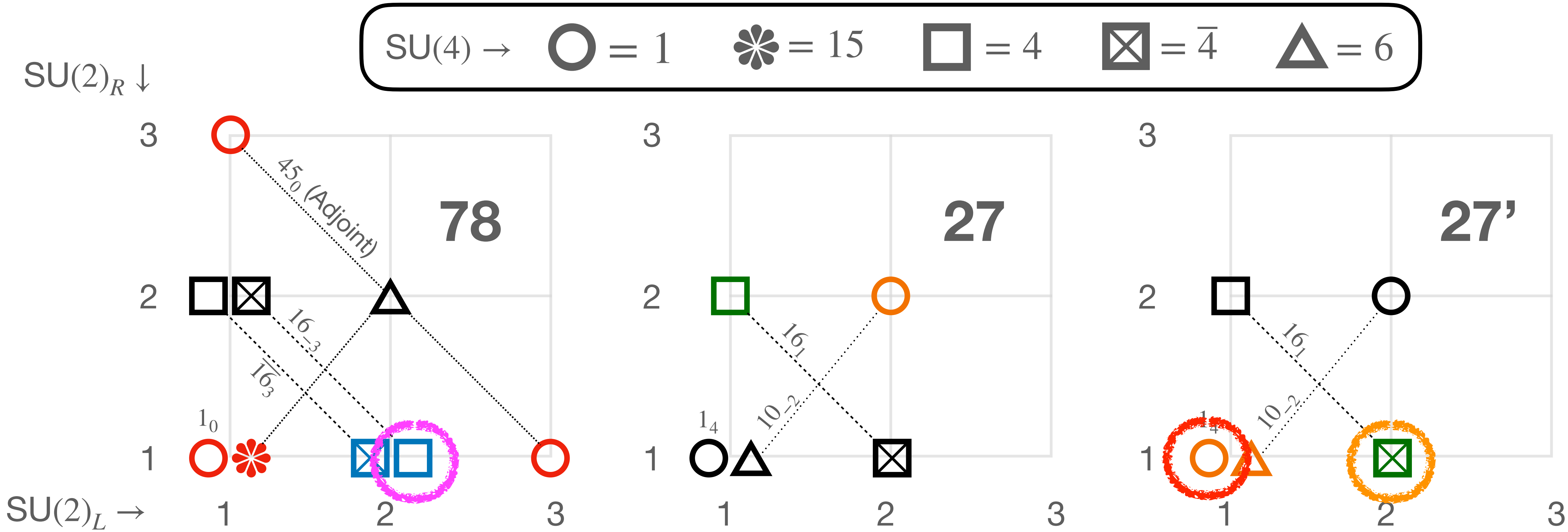

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-> Gives mass to unwanted Chiral states via U(1) breaking

Bulk interactions preserve Baryon number!

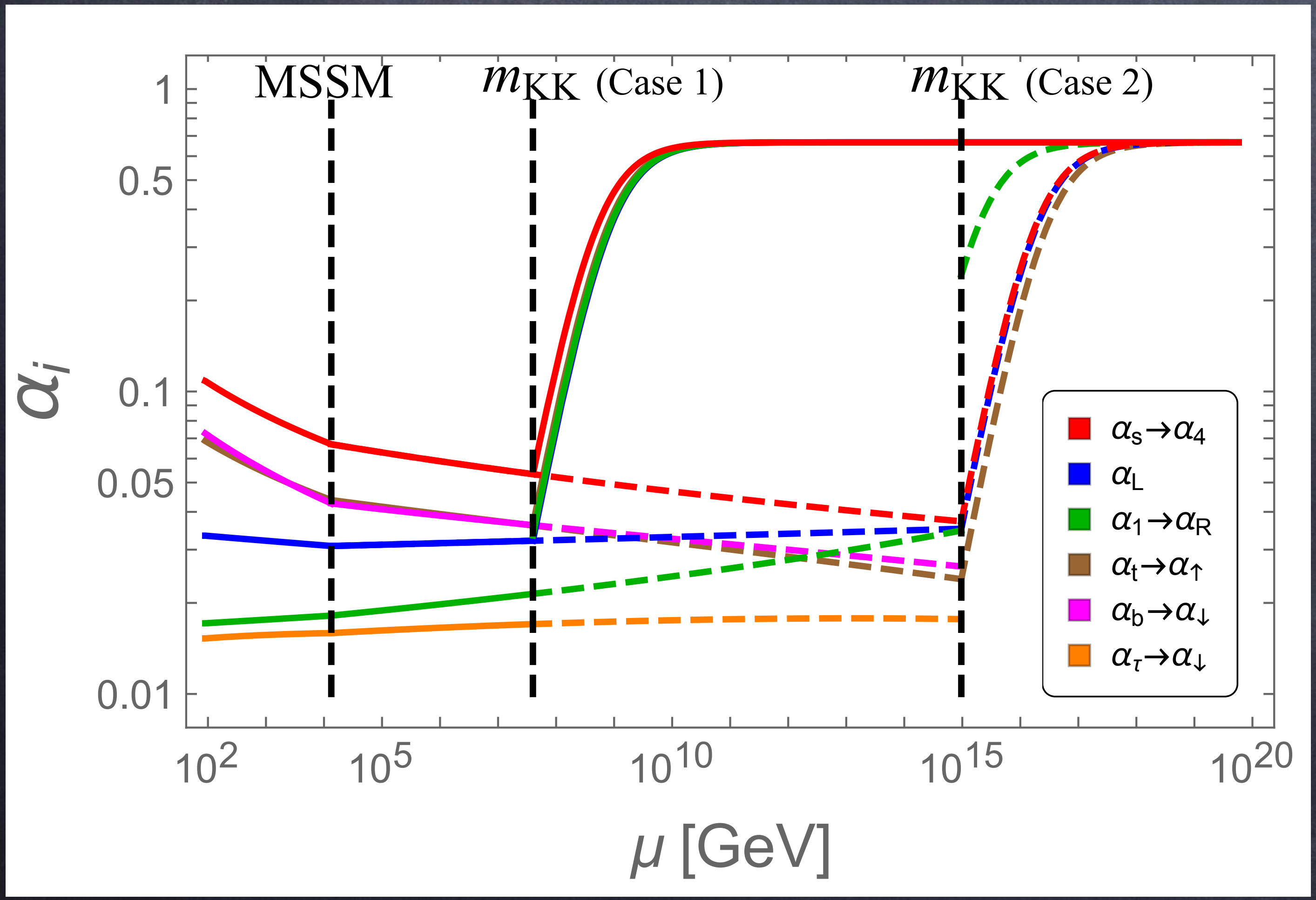
The fixed point

$$b_5 = -\frac{\pi}{2}\left(C(G) - \sum_i T_i(R_i)\right) = -3\pi$$

$$C(G) = 12 \quad T(27) = 3$$

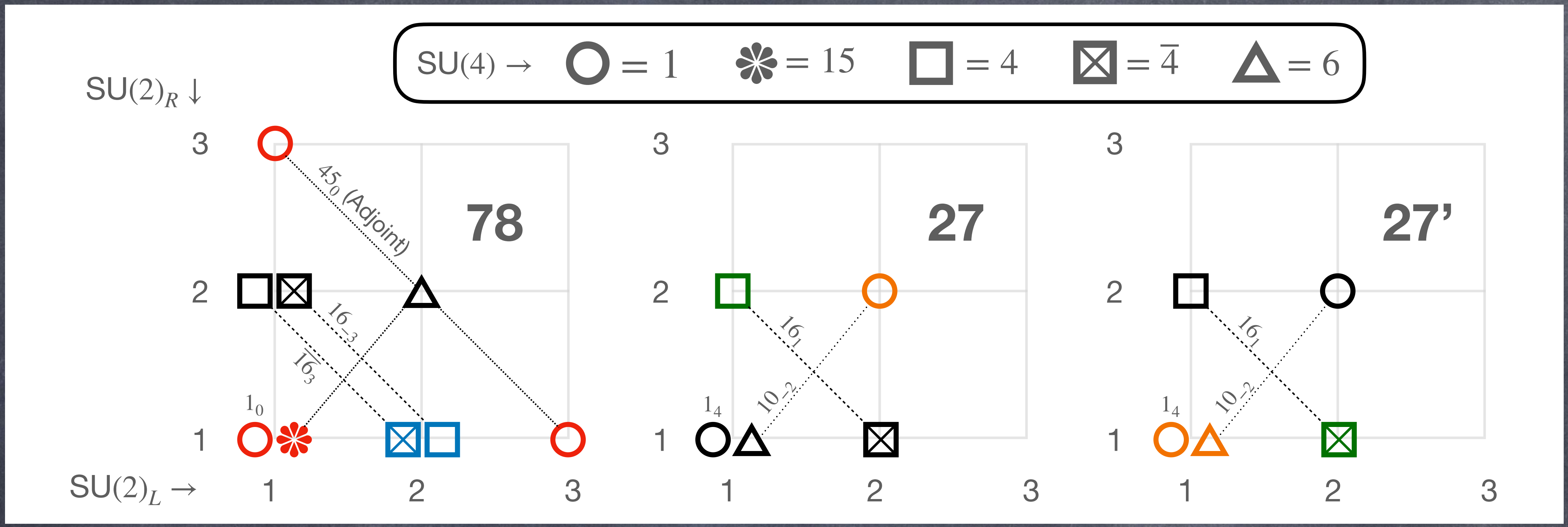
$$\tilde{\alpha}^* = \frac{2}{3}$$

No more than one generation allowed in the bulk!



- PS breaking due to a gauge-scalar
- U(1) breaking by singlet in 27′
- SUSY breaking to be studied

Predicting the light generations (from gauge anomalies)



- The zero modes generate an anomaly for the U(1) gauge symmetry:

$$\mathscr{A}_{16_1} - \mathscr{A}_{10_{-2}+1_4} = 2\mathscr{A}_{16_1}$$

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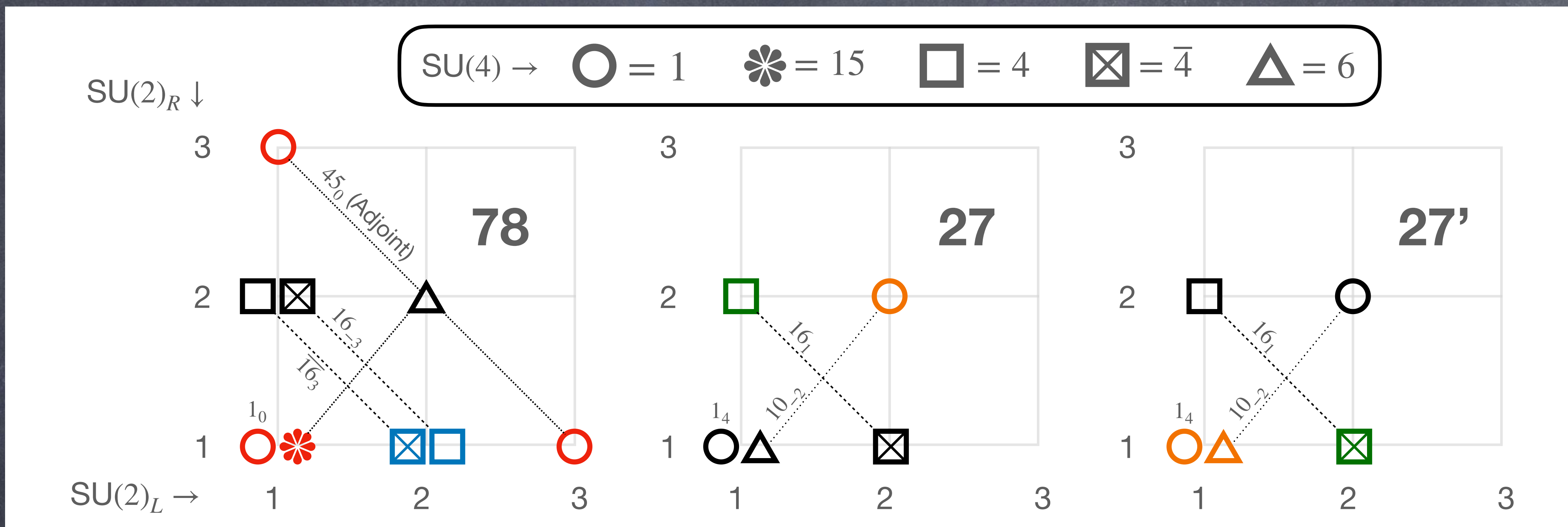
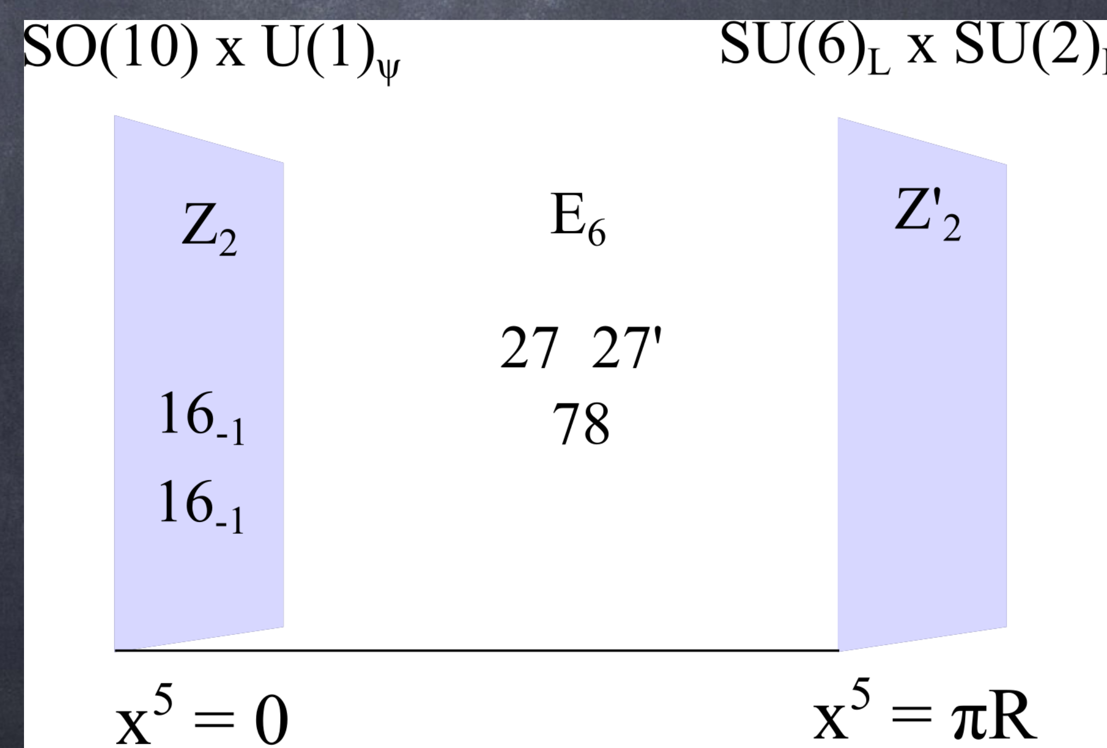


- The zero modes generate an anomaly for the U(1) gauge symmetry:

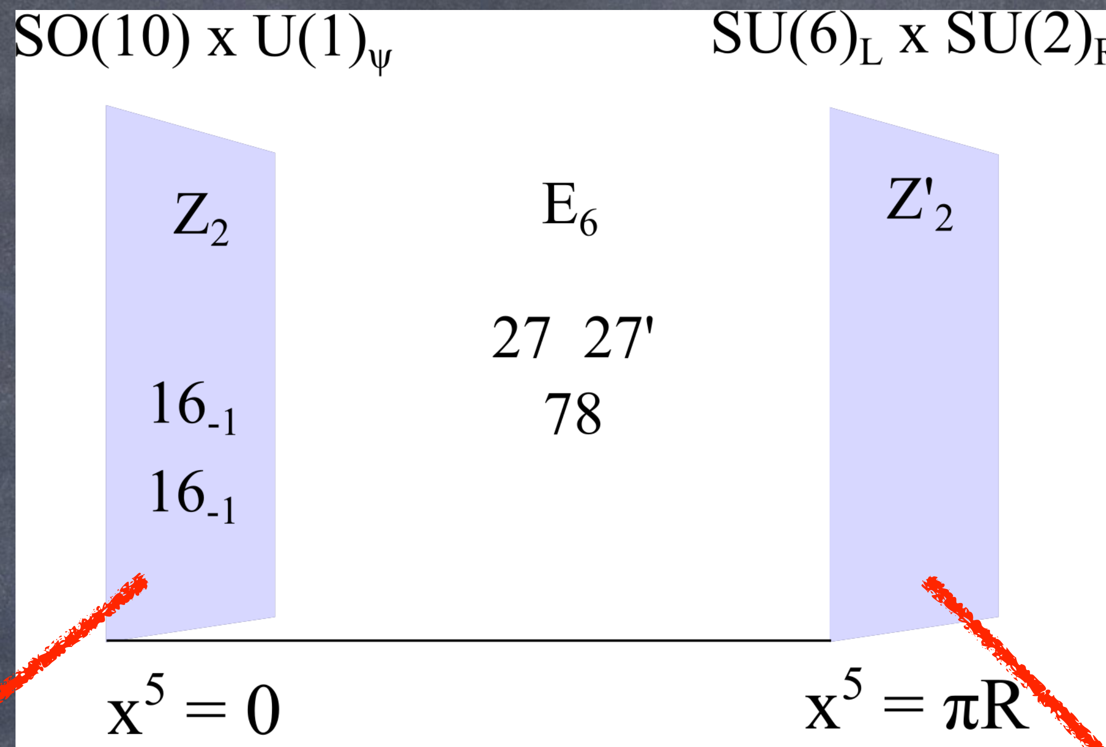
$$\mathscr{A}_{16_1} - \mathscr{A}_{10_{-2}+1_4} = 2\mathscr{A}_{16_1}$$

- Add exactly two generations on the SO(10) boundary!



Two model avenues:

SO(10) gens



One gen in (15,1)+(6,2)

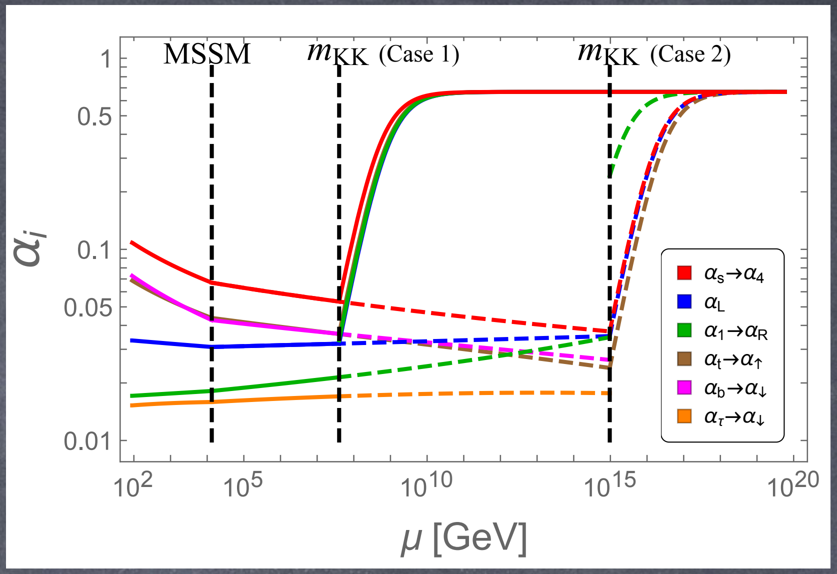
Model 1 :

- Predicts 2 generations
- "Usual" SO(10) model building allowed
- Scale pushed high by proton decay

Model 2 :

- Light generations preserve baryon number
- Number of generations not predicted
- Scale can be lowered (1000's TeV) from PS breaking

Conclusions and perspectives



- Asymptotic GUT is a novel paradigm, avoiding many shortcomings of traditional GUTs
- SUSY + bulk E6 allows to a-unify gauge and Yukawa couplings (for one generation)
- Two light generation PREDICTED by gauge anomalies on the SO(10) boundary - Model 1
- Low-scale possibility also allowed – Model 2
- Many aspects of phenomenology and model building remain to be explored!

Bonus tracks

The Yukawa sector runs

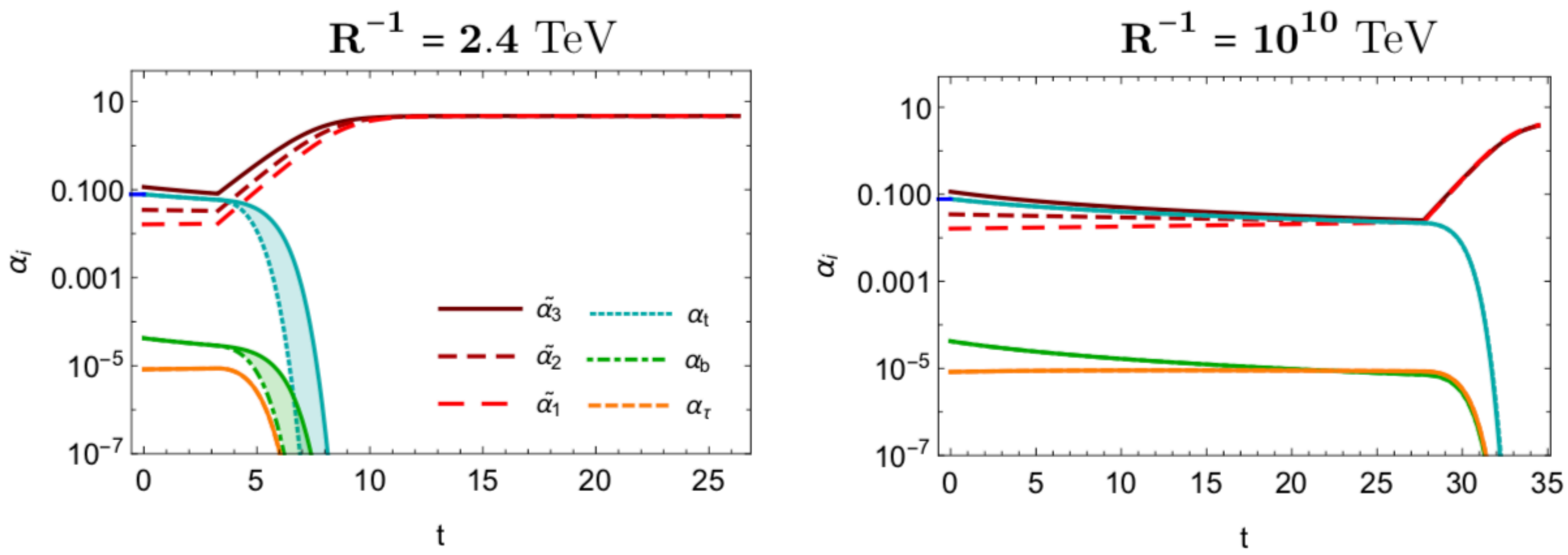


Figure 3. Running of the localized Yukawa couplings compared to the bulk gauge ones for two sample values of the compactification scale. The bands indicate the uncertainty related to KK gauge couplings (see text). The largest value of t corresponds to the 5D Planck mass value.

Localised Yukawas - SU(5) brane

Indalo states

Multiplets	Fields	L	B	Q	Q_3
$\psi_{\bar{5}}$	B_R^c	1/2	1/6	1/3	0
	τ_L	1	0	-1	-1
	ν_L	1	0	0	1
ψ_5	b_R	0	1/3	-1/3	0
	$\mathcal{T}_L^c$	-1/2	1/2	1	1
	$\mathcal{N}_L^c$	-1/2	1/2	0	-1
ψ_{10}	T_R^c	1/2	1/6	-2/3	0
	$\mathcal{T}_R^c$	-1/2	1/2	1	0
	t_L	0	1/3	2/3	1
	b_L	0	1/3	-1/3	-1
$\psi_{\overline{10}}$	t_R	0	1/3	2/3	0
	τ_R	1	0	-1	0
	T_L^c	1/2	1/6	-2/3	-1
	B_L^c	1/2	1/6	1/3	1
ψ_1	N	1	0	0	0
ϕ_5	H	1/2	-1/6	-1/3	0
	ϕ^+	0	0	1	1
	ϕ_0	0	0	0	-1
A_X	X	1/2	-1/6	-4/3	-1
	Y	1/2	-1/6	-1/3	1

- Non-SM components carry unusual B and L charges
- Hence, they cannot decay into SM states
- States with mass 1/R stable

 = Indalo

- Prehistoric symbol found in Almería caves, Spain
- It means "creation" or "nature" in Zulu

Indalo-genesis

Multiplets	Fields	L	B	Q	Q_3
$\psi_{\bar{5}}$	B_R^c	1/2	1/6	1/3	0
	τ_L	1	0	-1	-1
	ν_L	1	0	0	1
ψ_5	b_R	0	1/3	-1/3	0
	$\mathcal{T}_L^c$	-1/2	1/2	1	1
	$\mathcal{N}_L^c$	-1/2	1/2	0	-1
ψ_{10}	T_R^c	1/2	1/6	-2/3	0
	$\mathcal{T}_R^c$	-1/2	1/2	1	0
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	b_L	0	1/3	-1/3	-1
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	τ_R	1	0	-1	0
	T_L^c	1/2	1/6	-2/3	-1
	B_L^c	1/2	1/6	1/3	1
ψ_1	N	1	0	0	0
ϕ_5	H	1/2	-1/6	-1/3	0
	ϕ^+	0	0	1	1
	ϕ_0	0	0	0	-1
A_X	X	1/2	-1/6	-4/3	-1
	Y	1/2	-1/6	-1/3	1

- Baryogenesis could also produce an asymmetric abundance of Indalo states

Dark Matter candidate!

$1/R = 2.4\ TeV$