SU(5) aGUT : a minimal asymptotic unification model

Aldo Deandrea

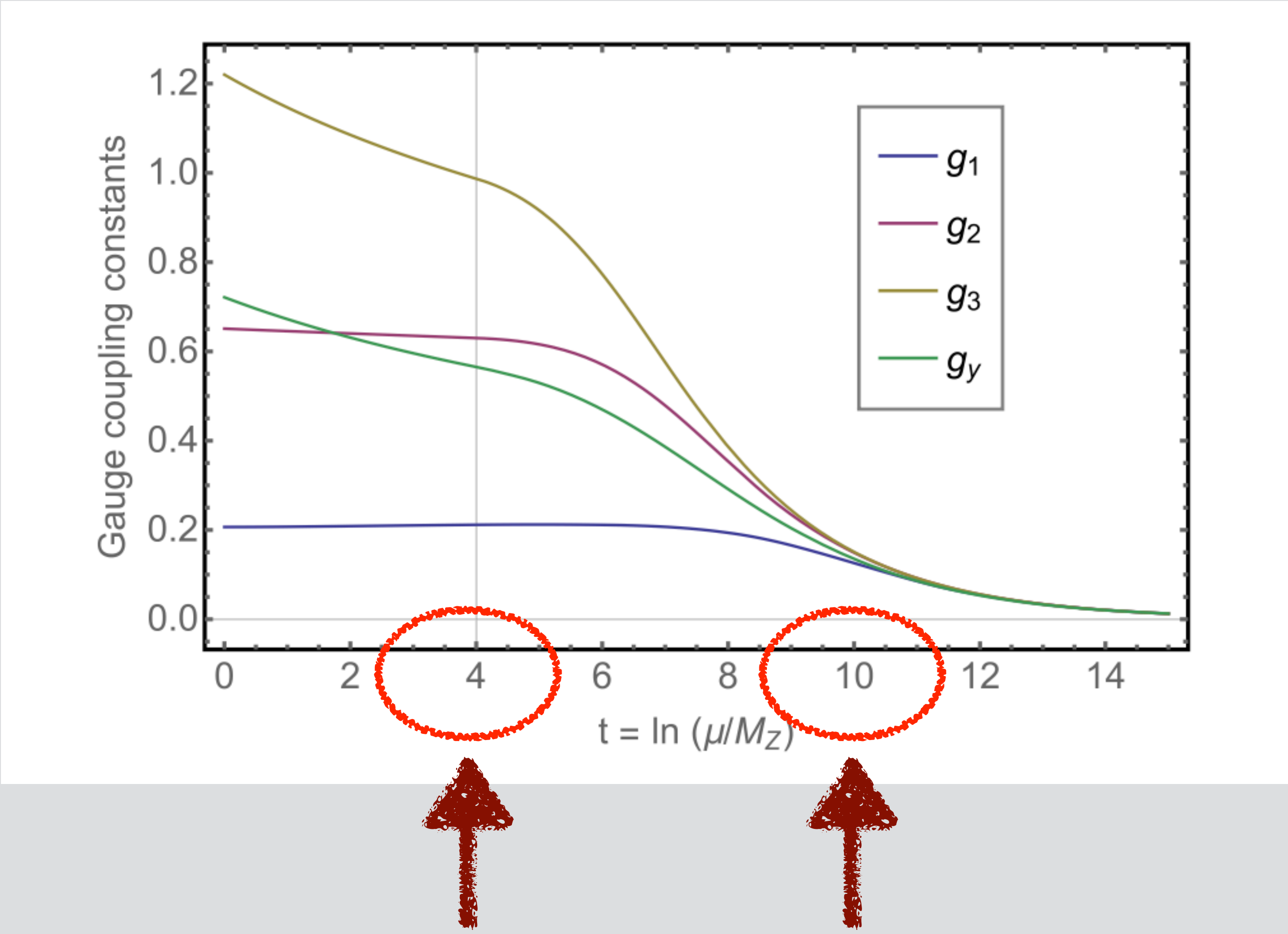
IP2I - Université Lyon 1

Planck 2022 - May 30th 2022

based on Phys.Lett. B776 (2018) 231-235 with Abdalgabar, Cacciapaglia, Cornell, Khojali and Phys. Rev. D104 (2021) 7, 075012 with Cacciapaglia, Cornell, Cot (2012.14732 [hep-th])

Asymptotic unification

Gauge couplings unification requires a specific scale and "crossing" of the evolution of couplings.
Asymptotic unification is NOT unification in the usual sense, rather at high energies, flow towards an UV fixed point.



Example in the EW sector with SU(3) ⊃ SU(2)xU(1) for gauge and Yukawa couplings (5D model)

1st KK mode kicks in at t ~4

"unification" sets around t~10 (~200 KK-modes)

A gauge scalar from extra dimensions

$$A_M = (A_\mu, A_5)$$

Under orbifold projection vectors and scalars have opposite parity

$$A_M^+ = (A_\mu^+, A_5^-)$$

Contains a zero mode vector

$$A_M^- = (A_\mu^-, A_5^+)$$

Contains a zero mode scalar

5D gauge symmetry broken by parity projection (but 4D preserved)

Higgs scalar "protected" by the gauge symmetry (Hosotani mechanism), vev "geometrisation"

A SU(3) toy model

SU(2) U(1)

$$A_M^+ : \frac{1}{\sqrt{2}} \begin{bmatrix} W_3/2 & W^+/\sqrt{2} & 0 \\ W^-/\sqrt{2} & -W_3/2 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \quad \frac{1}{2\sqrt{3}} \begin{bmatrix} B & 0 & 0 \\ 0 & B & 0 \\ 0 & 0 & -2B \end{bmatrix}$$

Higgs

$$A_M^- : \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & h^+ \\ 0 & 0 & h^0 \\ h^- & h^{0*} & 0 \end{bmatrix}$$

Fermion matter
bulk triplet

Weinberg angle, fermion mass

$$A_M^- : \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & h^+ \\ 0 & 0 & h^0 \\ h^- & h^{0*} & 0 \end{bmatrix}$$

Higgs doublet, but U(1) charge

$$\frac{1}{2\sqrt{3}}(1-(-2)) = \frac{\sqrt{3}}{2}$$

The group theory value for the Weinberg angle is not the correct one in SU(3)

$$g' = \sqrt{3}\, g \rightarrow \sin^2\theta_W = \frac{3}{4}$$

Fermion mass related to W mass

$$m_f = m_W$$

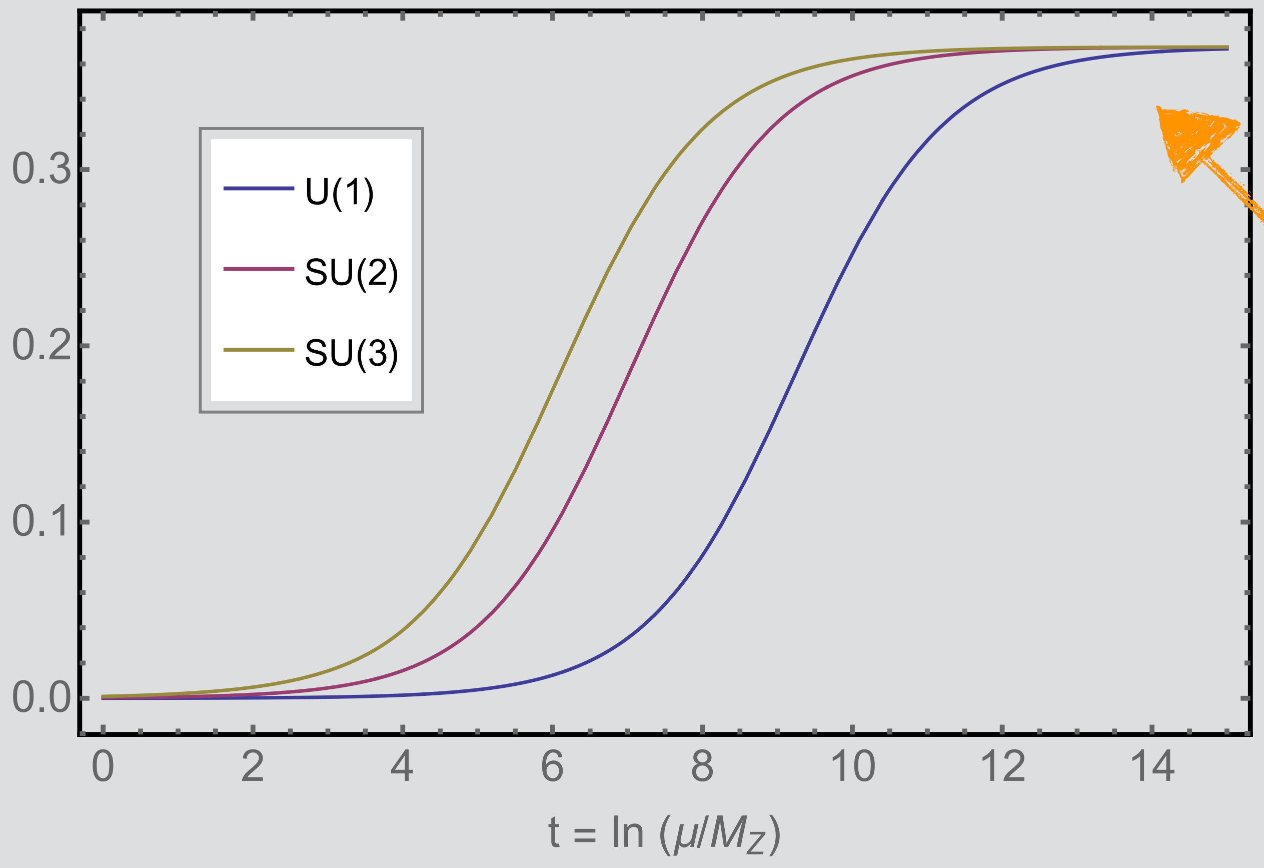
Renormalisation group evolution

- Group theory prediction is at unification, need to run down at the EW scale
- Λ and EW not that far, but running in Xdim is fast, linear effect, not log
- Here Yukawa coupling is also a gauge coupling

	$SU(2)_L$ g	$U(1)_Y$ g'	Yuk. y	$SU(3)_c$ g_s
SU(3) GHU	g_{GHU}	$\sqrt{3}\, g_{GHU}$	$g_{GHU}/\sqrt{2}$	–
SM	0.66	0.35	1.0	1.2

Running of the gauge couplings

$$16\pi^2 \, \frac{dg_i}{dt} = b_i^{\text{SM}} \, g_i^3 + (S(t) - 1) \, b_i^{\text{GHU}} \, g_i^3$$



S(t) encodes the sum of the KK contributions to the running

5d coupling is going to a constant ~ α₄ E (asymptotically safe)

$$b_i^{SM} = \left[\frac{41}{10}, -\frac{19}{6}, -7\right], \quad b_i^{SU(3)} = \left[-\frac{17}{6}, -\frac{17}{2}, -\frac{17}{2}\right]$$

Simplest aGUT : SU(5) embedding

- SU(5) gauge symmetry in the bulk, broken to SM, via orbifold boundary conditions

- A single extra dimension compactified on an orbifold

  $S^1/\mathbb{Z}_2 \times \mathbb{Z}_2'$

- SM matter multiplets are NOT the usual SU(5) ones due to boundary conditions, need to duplicate the usual structure $\bar{5} + 10$

- this model naturally produces a "fake GUT" (see K.Watanabe talk)

Fermion non-unification

- Capital letter fields are the new “Indalo” fields
- Baryon and Lepton charge conserved
- No proton decay
- Dark matter candidate → Lightest Indalo S

$$\psi_{1_{L/R}} = N, \qquad \psi_{5_{L/R}} = \begin{pmatrix} b \\ L^c \end{pmatrix}_{L/R}, \qquad \psi_{\bar{5}_{L/R}} = \begin{pmatrix} B^c \\ l \end{pmatrix}_{L/R},$$

$$\psi_{10_{L/R}} = \frac{1}{\sqrt{2}} \begin{pmatrix} T^c & q \\ & \mathcal{T}^c \end{pmatrix}_{L/R}, \qquad \psi_{\overline{10}_{L/R}} = \frac{1}{\sqrt{2}} \begin{pmatrix} t & Q^c \\ & \tau \end{pmatrix}_{L/R},$$

Particle content overview

Field	$(\mathbb{Z}_2, \mathbb{Z}_2')$	SM	Zero mode?	KK mass
l	$(+,+)$	$(\mathbf{1}, \mathbf{2}, -1/2)$	✓	$2/R$
L	$(+,-)$		–	$1/R$
τ	$(-,-)$	$(\mathbf{1}, \mathbf{1}, -1)$	✓	$2/R$
$\mathcal{T}$	$(-,+)$		–	$1/R$
N	$(-,-)$	$(\mathbf{1}, \mathbf{1}, 0)$	✓	$2/R$
q	$(+,+)$	$(\mathbf{3}, \mathbf{2}, 1/6)$	✓	$2/R$
Q	$(+,-)$		–	$1/R$
t	$(-,-)$	$(\mathbf{3}, \mathbf{1}, 2/3)$	✓	$2/R$
T	$(-,+)$		–	$1/R$
b	$(-,-)$	$(\mathbf{3}, \mathbf{1}, -1/3)$	✓	$2/R$
B	$(-,+)$		–	$1/R$
ϕ_h	$(+,+)$	$(\mathbf{1}, \mathbf{2}, 1/2)$	✓	$2/R$
H	$(-,+)$	$(\mathbf{3}, \mathbf{1}, -1/3)$	–	$1/R$
B_μ		$(\mathbf{1}, \mathbf{1}, 0)$		
W_μ^a	$(+,+)$	$(\mathbf{1}, \mathbf{3}, 0)$	✓	$2/R$
G_μ^i		$(\mathbf{8}, \mathbf{1}, 0)$		
A_X^μ	$(-,+)$	$(\mathbf{3}, \mathbf{2}, -5/6)$	–	$1/R$

Yukawa non-unification

$$\overline{\psi_1}\psi_{\bar{5}}\phi_5 = \overline{N}\phi_h l + \overline{N}H\mathcal{B}^c,$$

$$\sqrt{2}\bar{\psi}_5\psi_{10}\phi_5^* = \bar{b}\phi_h^* q - \bar{L}^c H^* q - \bar{L}^c\phi_h^*\mathcal{T}^c + \epsilon_3\bar{b}H^*T^c,$$

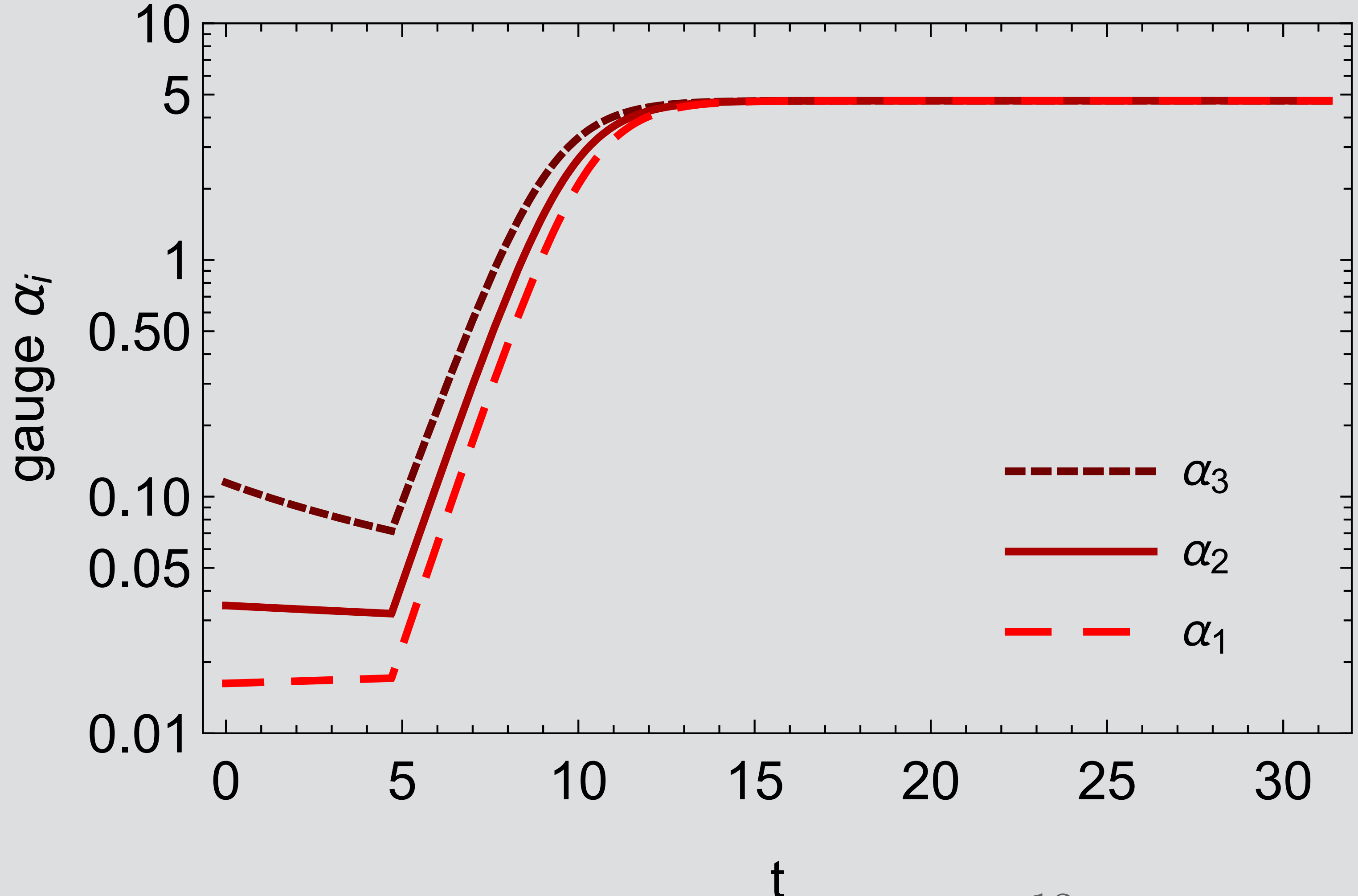
$$\sqrt{2}\overline{\psi_{\overline{10}}}\psi_{\bar{5}}\phi_5^* = -\bar{\tau}\phi_h^* l - \bar{Q}^c H^* l + \bar{Q}^c\phi_h^* B^c - \epsilon_3\bar{t}H^*B^c,$$

$$\frac{1}{2}\epsilon_5\overline{\psi_{\overline{10}}}\psi_{10}\phi_5 = \bar{t}\phi_h q + \bar{t}H\mathcal{T}^c + \bar{\tau}HT^c + \overline{Q^c}\phi_h T^c + \epsilon_3\bar{Q}^c H q,$$

4 independent couplings, one for each SM Yukawa term

RGE SU(5) aGUT running

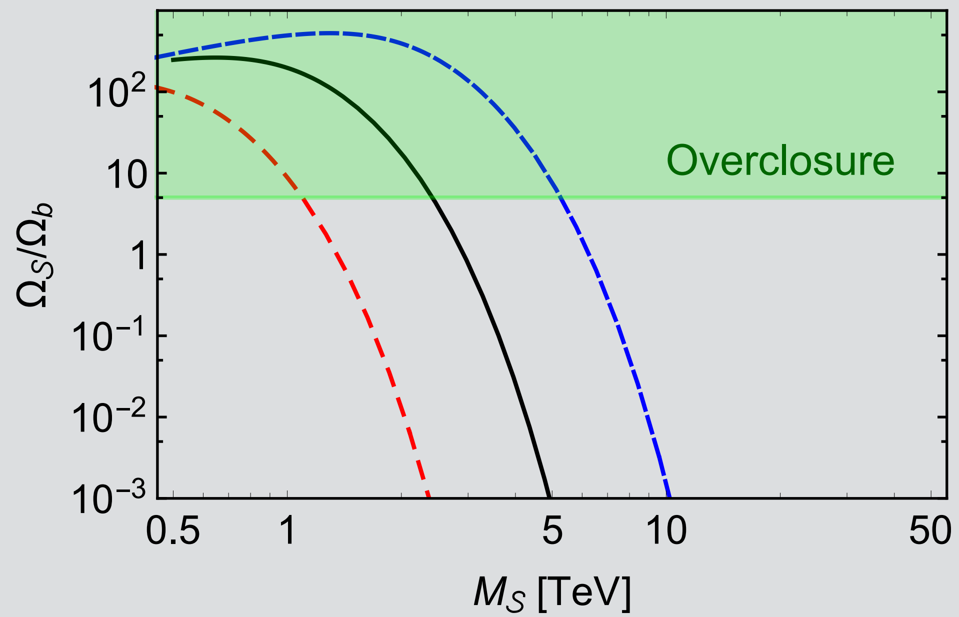
- All couplings constants flow to the same non-zero UV fixed point (- $2\pi/b_5$) asymptotically.
- Extra-dimensional one-loop factor is perturbative



$$b_5 = -\frac{52}{3} + \frac{16}{3} n_g$$

n_g number of fermion generations in the bulk

Baryogenesis, Indalogenesis and DM



assuming 1st order phase transition

- Indalo  particles carry both B and L charges, in values that are half of the SM unit charges
- It is not possible for them to decay into SM fields only and no proton decay
- The lightest state S is stable and a candidate for dark matter
- After the Indalo particles exit thermal equilibrium with the SM, they decay S + SM, and release some baryon number to the SM sector

Conclusions

- New paradigm on (asymptotic) unification (aGUT)
- A (X-Dim) motivated example of fake-GUT
- No proton decay
- Yukawa evolution constrained
- A dark Matter candidate (the lightest -field S)
- Baryogenesis can be reproduced (typical mass 2-6 TeV)
- Flavour observables under study