(Non) SUSY Adjoint SU(5)

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References:

"Renormalizable Adjoint SU(5)," arXiv:hep-ph/0702287

"Supersymmetric Adjoint SU(5)," arXiv:0705.3589 [hep-ph]

Aim

What is the simplest renormalizable (susy) grand unified theory based on the SU(5) gauge symmetry ?

Contents

Georgi-Glashow Model

Georgi, Glashow, Phys.Rev.Lett.32:438,1974

$$SU(3) \bigotimes SU(2) \bigotimes U(1) \subset SU(5)$$

$$\alpha_3 \qquad \alpha_2 \qquad \alpha_1 \qquad \longrightarrow \qquad \alpha_{GUT}$$

$$24_G = \underbrace{(8,1,0)}_{G^a} \bigoplus \underbrace{(1,3,0)}_{W^b} \bigoplus \underbrace{(3,2,-5/6)}_{\overline{V}} \bigoplus \underbrace{(\bar{3},2,5/6)}_{V} \bigoplus \underbrace{(1,1,0)}_{B}$$

$$\bar{5} = \underbrace{(\bar{3}_C, 1_L, 1/3)}_{d^C} \bigoplus \underbrace{(1_C, 2_L, -1/2)}_{(\nu,e)}$$

$$10 = \underbrace{(\bar{3}_C, 1_L, -2/3)}_{u^C} \bigoplus \underbrace{(3_C, 2_L, 1/6)}_{(u,d)} \bigoplus \underbrace{(1_C, 1_L, 1)}_{e^C}$$

$$5_H = \underbrace{(3_C, 1_L, -1/3)}_{T} \bigoplus \underbrace{(1_C, 2_L, 1/2)}_{H}$$

$$24_H = \underbrace{(8_C, 1_L, 0)}_{\Sigma_8} \bigoplus \underbrace{(1_C, 3_L, 0)}_{\Sigma_3} \bigoplus \underbrace{(3_C, 2_L, -5/6)}_{\Sigma_{(3,2)}}$$

$$\bigoplus \underbrace{(\bar{3}_C, 2_L, 5/6)}_{\Sigma_{(\bar{3},2)}} \bigoplus \underbrace{(1_C, 1_L, 0)}_{\Sigma_{24}}$$

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Why the Georgi-Glashow model is ruled out ?

- Unification of gauge couplings in disagreement with the values of α_s, $\sin\theta_W$ and α_{em} at the electroweak scale

- $M_E = M_D^T$ at the GUT scale

- $M_\nu = 0$

UNIFICATION CONSTRAINTS

$$\alpha_i^{-1}(M_Z) = \alpha_{GUT}^{-1} + \frac{B_i}{2\pi} \; ln \; M_{GUT}/M_Z$$

i=1,2,3 for $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$

$$B_i = b_i^{SM} + \sum_I b_{iI} \, r_I, \qquad r_I = \frac{ln \; M_{GUT}/M_I}{ln \; M_{GUT}/M_Z}$$

$0 \leq r_I \leq 1 \qquad M_Z \leq M_I \leq M_{GUT}$

$$b_1^{SM} = 41/10, \quad b_2^{SM} = -19/6, \quad b_3^{SM} = -7$$

$\sin^2\theta_W = g_1^2/(g_1^2 + g_2^2), \qquad e = g_2 \sin\theta_W$

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$$\frac{B_2-B_3}{B_1-B_2} = \frac{5}{8}\frac{\left(\sin^2\theta_W(M_Z)-\alpha_{em}(M_Z)/\alpha_s(M_Z)\right)}{\left(3/8-\sin^2\theta_W(M_Z)\right)} = 0.716$$

$$ln\ M_{GUT}/M_Z = \frac{16\pi}{5\alpha_{em}(M_Z)}\frac{\left(3/8-\sin^2\theta_W(M_Z)\right)}{(B_1-B_2)} = 184.9/(B_1 - B_2)$$

Using $\alpha_s(M_Z) = 0.1176 \quad \alpha_{em}^{-1}(M_Z) = 127.906 \quad \sin^2\theta_W(M_Z) = 0.2312$

$$B_1^{SU(5)} = b_1^{SM} - \frac{105}{6}r_V + \frac{1}{15}r_T$$

$$B_2^{SU(5)} = b_2^{SM} + \frac{1}{3}r_{\Sigma_3} - \frac{21}{2}r_V$$

$$B_3^{SU(5)} = b_3^{SM} + \frac{1}{2}r_{\Sigma_8} - 7\ r_V + \frac{1}{6}r_T$$

	SM	T	Σ_8	Σ_3
B_{23}	$\frac{23}{6}$	$-\frac{1}{6}r_T$	$-\frac{1}{2}r_{\Sigma_8}$	$\frac{1}{3}r_{\Sigma_3}$
B_{12}	$\frac{109}{15}$	$\frac{1}{15}r_T$	0	$-\frac{1}{3}r_{\Sigma_3}$

$$B_{23}^{SM}/B_{12}^{SM} = 0.53, \quad B_{23}^{GG}/B_{12}^{GG} \leq 0.60$$

The Georgi-Glashow model is ruled out !

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FERMION MASSES

Relation between Charged Fermion Masses: $M_D = M_E^T$

- $45_H \quad \longrightarrow \quad \mathrm{Y}_1 10 \ \bar{5} \ 5_H^* \ + \ Y_2 10 \ \bar{5} \ 45_H^*$ (Georgi, Jarlskog'79)

  $M_D - M_E^T = 8 Y_2 v_{45}^*$

- Higher-dimensional operators

  $Y_1 10 \ \bar{5} \ 5_H^* \ + \ Y_2 10 \ 24_H \ \bar{5} \ 5_H^* / \Lambda$

Neutrino Masses: $M_\nu = 0$

- Type I seesaw mechanism: fermionic singlets 1_i, i=1,2,..
  Minkowski; Yanagida; Gell-Mann, Ramond, Slansky; Glashow; Mohapatra, Senjanović
- Type II seesaw mechanism: $\Delta \subset 15_H$, $SU(2)_L$ scalar triplet
  Lazarides, Shafi, Wetterich; Schechter, Valle; Mohapatra, Senjanović
- Type III seesaw mechanism: $\rho \subset 24$, $SU(2)_L$ fermionic triplet
  Foot, Lew, He, Joshi; Ma.

Doublet-Triplet Splitting Problem: Why $M_T >> M_H$?

$M_H \leq 200$ GeV from EW Precision tests (see ex: W. Hollik '06)

and $M_T > 10^{11}$ GeV from proton decay

Minimal Supersymmetric $SU(5)$

S. Dimopoulos, H. Georgi, Nucl.Phys.B **193** (1981) 150 ; N. Sakai Z.Phys.C **11** (1981) 153

Chiral Superfields:

Fermions: $\hat{\bar{5}}_i$, $\hat{10}_i$ Higgses: $\hat{5}_H$, $\hat{\bar{5}}_H$, $\hat{24}_H$

Vector Superfields: $\hat{24}_G$

$$\hat{10} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & \hat{U}_3^C & -\hat{U}_2^C & \hat{U}_1 & \hat{D}_1 \\ -\hat{U}_3^C & 0 & \hat{U}_1^C & \hat{U}_2 & \hat{U}_2 \\ \hat{U}_2^C & -\hat{U}_1^C & 0 & \hat{U}_3 & \hat{D}_3 \\ -\hat{U}_1 & -\hat{U}_2 & -\hat{U}_3 & 0 & \hat{E}^C \\ -\hat{D}_1 & -\hat{D}_2 & -\hat{D}_3 & -\hat{E}^C & 0 \end{pmatrix}$$

$$\hat{\bar{5}} = \begin{pmatrix} \hat{D}_1^C \\ \hat{D}_2^C \\ \hat{D}_3^C \\ \hat{E} \\ -\hat{N} \end{pmatrix} \quad \hat{5}_H = \begin{pmatrix} \hat{T}_1 \\ \hat{T}_2 \\ \hat{T}_3 \\ \hat{H}_2^+ \\ \hat{H}_2^0 \end{pmatrix} \quad \hat{\bar{5}}_H = \begin{pmatrix} \hat{\bar{T}}_1 \\ \hat{\bar{T}}_2 \\ \hat{\bar{T}}_3 \\ \hat{H}_1^- \\ -\hat{H}_1^0 \end{pmatrix}$$

$$\hat{24}_H = \begin{pmatrix} \hat{\Sigma}_8 & \hat{\Sigma}_{(3,2)} \\ \hat{\Sigma}_{(\bar{3},2)} & \hat{\Sigma}_3 \end{pmatrix} + \frac{1}{2\sqrt{15}} \begin{pmatrix} 2 & 0 \\ 0 & -3 \end{pmatrix} \hat{\Sigma}_{24}$$

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Is the Minimal Renormalizable SUSY SU(5) ruled out?

- Unification: O.K.
- $M_E = M_D^T$ $(b - \tau$ unification O.K.; see ex: G. Ross, M. Serna '07)
- $M_\nu = 0$ (if R-parity is conserved)

The Minimal Renormalizable SUSY $SU(5)$ is ruled out !!

Fermion Masses:

- $M_D = M_E^T$ $(b - \tau$ unification is O.K.)

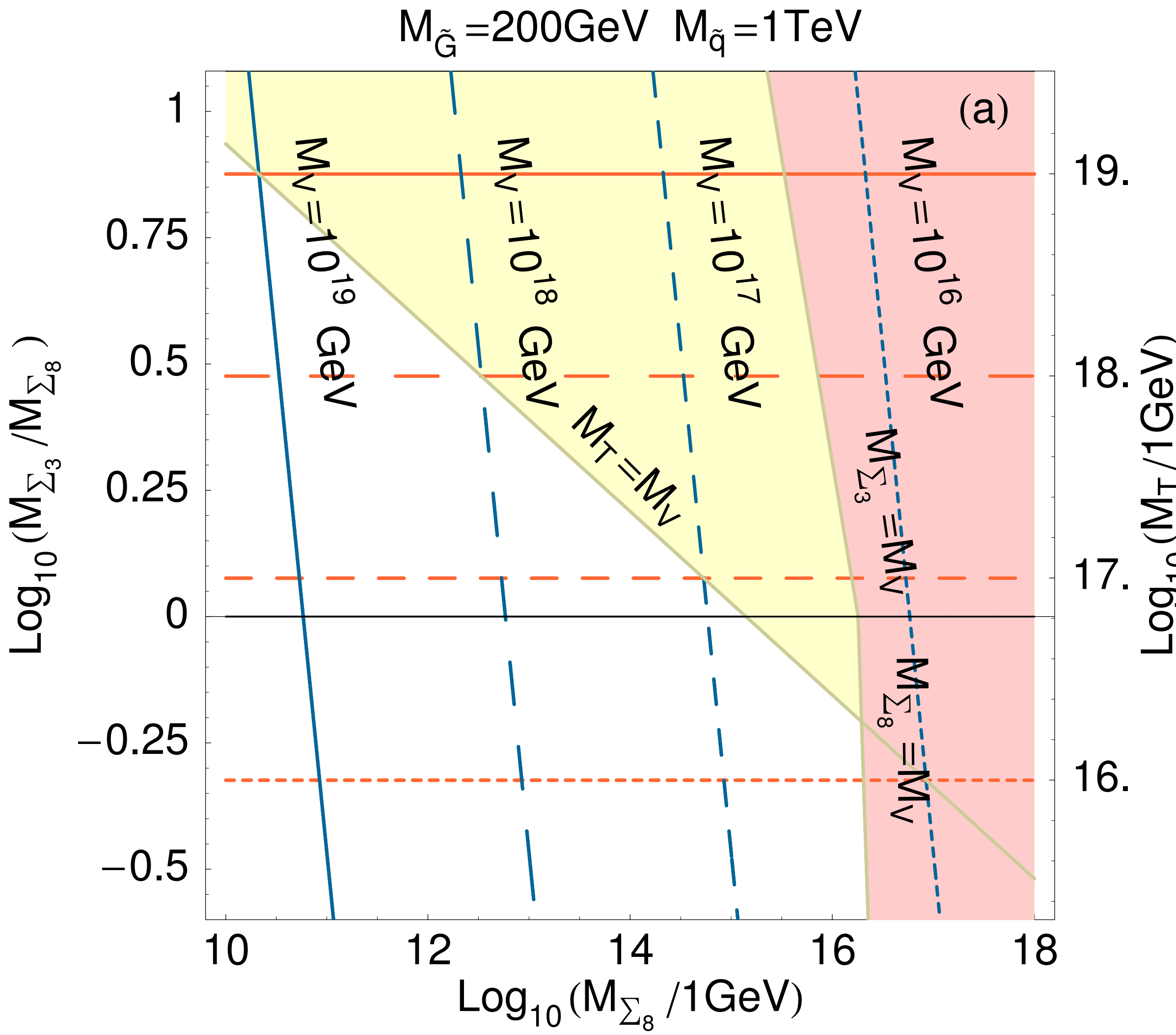
$\hat{45}_H \bigoplus \overline{\hat{45}}_H \rightarrow \mathrm{Y}_1 \hat{10}\ \hat{\bar{5}}\ \hat{\bar{5}}_H + Y_2 \hat{10}\ \hat{\bar{5}}\ \overline{\hat{45}}_H$

$M_D - M_E^T = 8 Y_2 v_{\overline{45}}$

- Higher-dimensional operators

$Y_1\ \hat{10}\ \hat{\bar{5}}\ \hat{\bar{5}}_H + Y_2\ \hat{10}\ \hat{24}_H\ \hat{\bar{5}}\ \hat{\bar{5}}_H / \Lambda$

see ex: P. Nath'95, '96 ; Bajc, P. F. P, Senjanović'02



$M_{\tilde{G}}$ =200GeV $M_{\tilde{q}}$ =1TeV
(a)
$M_V = 10^{19}$ GeV
$M_V = 10^{18}$ GeV
$M_V = 10^{17}$ GeV
$M_V = 10^{16}$ GeV
$M_T = M_V$
$M_{\Sigma_3} = M_V$
$M_{\Sigma_8} = M_V$
$\mathrm{Log}_{10}(M_{\Sigma_3}/M_{\Sigma_8})$
$\mathrm{Log}_{10}(M_T/1\mathrm{GeV})$
$\mathrm{Log}_{10}(M_{\Sigma_8}/1\mathrm{GeV})$
1
0.75
0.5
0.25
0
−0.25
−0.5
19.
18.
17.
16.
10
12
14
16
18

Neutrino Masses

- R-parity violation

  $\mathcal{W}_{NR} = \epsilon_i \; \hat{\bar{5}}_i \; \hat{5}_H \; + \; \lambda_{ijk} \; \hat{10}_i \; \hat{\bar{5}}_j \; \hat{\bar{5}}_k \; + \; \delta_i \; \hat{\bar{5}}_i \; \hat{24}_H \; \hat{5}_H$

- Type I seesaw mechanism (Minkowski; Yanagida; Gell-Mann, Ramond, Slansky; Glashow; Mohapatra, Senjanović): fermionic singlets 1_i

  $\mathcal{W}_\nu = Y_\nu^{ij} \hat{\bar{5}}_i \hat{5}_H \hat{1}_j \; + \; M_{ij} \hat{1}_i \hat{1}_j$

- Type II seesaw mechanism (Lazarides, Shafi, Wetterich; Schechter, Valle; Mohapatra, Senjanović): $\Delta \subset \hat{15}_H$, $SU(2)_L$ scalar triplet

  $\hat{15}_H \bigoplus \hat{\overline{15}}_H \; \rightarrow \mathrm{W}_\nu = Y_\nu^{ij} \; \hat{\bar{5}}_i \; \hat{\bar{5}}_j \; \hat{15}_H \; + \mu \; \hat{\bar{5}}_H \; \hat{\bar{5}}_H \; \hat{15}_H$

- Type III seesaw mechanism (Foot, Lew, He, Joshi; Ma): $\rho \subset \hat{24}$, $SU(2)_L$ fermionic triplet

  $\mathcal{W}_\nu = \lambda_\nu^i \; \hat{\bar{5}}_i \; \hat{24} \; \hat{5}_H \; + \; M_{24} \; Tr \; \hat{24}^2$

  Actually we have type I and type III seesaw mechanisms and only one neutrino is massive !!

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Realistic

Non-Supersymmetric

Grand Unified Theories

based on $SU(5)$

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Minimal Realistic Non-SUSY $SU(5)$

I. Dorsner, P.F.P Nucl.Phys.B723:53-76,2005

Matter: $\bar{5} = (d^C, e, \nu)$, $10 = (u^C, Q, e^C)$

Higgs Sector: 5_H, 24_H, 15_H

$$15 = \underbrace{(1,3,1)}_{\Phi_a} \bigoplus \underbrace{(3,2,1/6)}_{\Phi_b} \bigoplus \underbrace{(6,1,-2/3)}_{\Phi_c}$$

Neutrino Mass through the Type II seesaw mechanism:

$$Y_\nu \; \bar{5} \; \bar{5} \; 15_H \; + \; \mu \; 5_H^* \; 5_H^* \; 15_H + \text{h.c.}$$

$$M_\nu = Y_\nu < \Phi_a >= Y_\nu \; \mu \; v_W^2 / M_\Delta^2$$

Charged Fermion Masses: $Y_E \neq Y_D^T$ using h.d.ops

Unification: O.K. The theory predicts a light scalar leptoquark Φ_b

See also: I. Dorsner, P.F.P, R. González Felipe, Nucl.Phys.B747:312-327,2006
I. Dorsner, P.F.P, G. Rodrigo, Phys.Rev.D75:125007,2007

$\tau_p < 2 \times 10^{36}$ years

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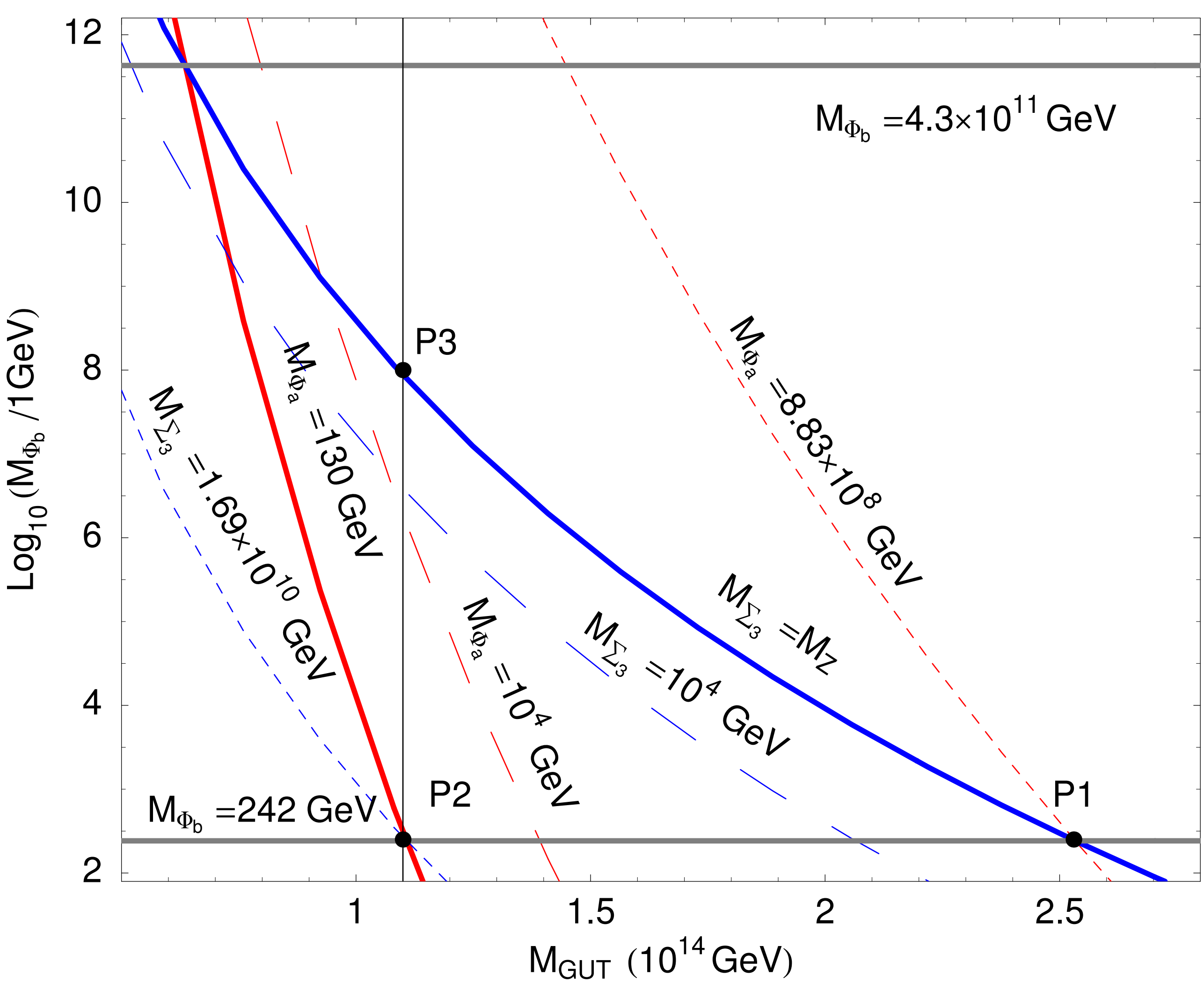
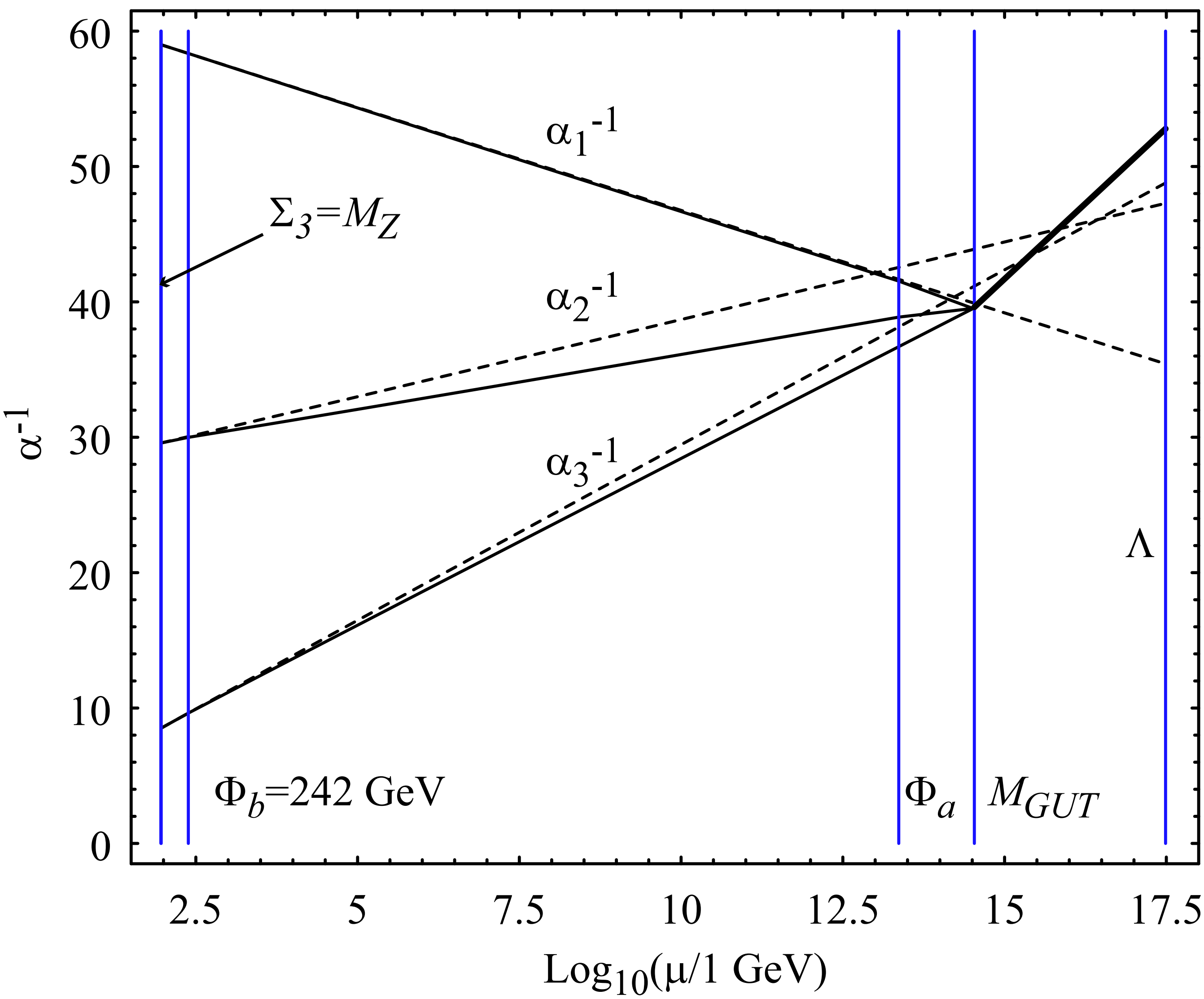

M_{Φ_b} =4.3×10^{11} GeV
P3
P2
P1
M_{Φ_a} =130 GeV
M_{Φ_a} =8.83×10^{8} GeV
M_{Σ_3} =1.69×10^{10} GeV
M_{Σ_3} =M_Z
M_{Φ_a} =10^{4} GeV
M_{Σ_3} =10^{4} GeV
M_{Φ_b} =242 GeV
$Log_{10}(M_{\Phi_b}$ /1GeV)
M_{GUT} (10^{14} GeV)
12
10
8
6
4
2
1
1.5
2
2.5

I. Dorsner, P.F.P, G. Rodrigo, Phys.Rev.D75:125007,2007



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Type III seesaw and Grand Unification

Type III seesaw mechanism (Foot, Lew, He and Joshi'89):

ρ is a $SU(2)_L$ fermionic triplet

Type III seesaw and SUSY SU(5) Unification (Ma'98): $\rho \subset \hat{24}$

$$\mathcal{W}_\nu = \lambda_\nu^i \ \hat{\bar{5}}_i \ \hat{24} \ \hat{5}_H \ + \ M_{24} \ Tr \ \hat{24}^2$$

Actually we have type I and type III seesaw mechanisms and only one neutrino is massive !!

$$\hat{24} = \underbrace{(8,1,0)}_{\hat{\rho}_8} \bigoplus \underbrace{(1,3,0)}_{\hat{\rho}_3} \bigoplus \underbrace{(3,2,-5/6)}_{\hat{\rho}_{(3,2)}} \bigoplus \underbrace{(\bar{3},2,5/6)}_{\hat{\rho}_{(\bar{3},2)}} \bigoplus \underbrace{(1,1,0)}_{\hat{\rho}_0}$$

Type III seesaw and Non-SUSY Unification

B. Bajc, G. Senjanović, hep-ph/0612029

Matter: $\bar{5} = (d^C, e, \nu)$, $10 = (u^C, Q, e^C)$, 24

Higgs Sector: 5_H, 24_H

$$24 = \underbrace{(8,1,0)}_{\rho_8} \bigoplus \underbrace{(1,3,0)}_{\rho_3} \bigoplus \underbrace{(3,2,-5/6)}_{\rho_{(3,2)}} \bigoplus \underbrace{(\bar{3},2,5/6)}_{\rho_{(\bar{3},2)}} \bigoplus \underbrace{(1,1,0)}_{\rho_0}$$

Neutrino Mass:

$$Y_0^i \, \bar{5}_i \, 24 \, 5_H \; + \; \frac{1}{\Lambda} \, \bar{5}_i \times (\; Y_1^i \, 24 \, 24_H \; + \; Y_2^i \, 24_H \, 24 \, + \; Y_3^i \, Tr(24 \; 24_H)) \; 5_H$$

Charged Fermion Masses: $Y_E \neq Y_D^T$ using higher-dimensional operators

Unification: O.K. The theory predicts a light fermionic SU(2) triplet ρ_3

See also: I. Dorsner, P.F.P, JHEP 0706:029,2007.

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Renormalizable Adjoint $SU(5)$

P. F. P., hep-ph/0702287

Matter: $\bar{5} = (d^C, e, \nu)$, $10 = (u^C, Q, e^C)$, 24

Higgs Sector: 5_H, 24_H, 45_H

$$24 = \underbrace{(8,1,0)}_{\rho_8} \oplus \underbrace{(1,3,0)}_{\rho_3} \oplus \underbrace{(3,2,-5/6)}_{\rho_{(3,2)}} \oplus \underbrace{(\bar{3},2,5/6)}_{\rho_{(\bar{3},2)}} \oplus \underbrace{(1,1,0)}_{\rho_0}$$

Neutrino masses through Type I and Type III seesaw mechanisms:

$$V_\nu = c_i \, \bar{5}_i \, 24 \, 5_H \, + \, p_i \, \bar{5}_i \, 24 \, 45_H \, + \, h.c.$$

$$M_\nu^{ij} = a^i \, a^j / M_{\rho_3} \, + \, b^i \, b^j / M_{\rho_0}$$

Charged Fermion Masses: $Y_E \neq Y_D^T$ using 45_H

$$V_{de} = 10 \, \bar{5} \, (Y_1 \, 5_H^* \, + \, Y_2 \, 45_H^*) \, + \, h.c.$$

i) *Renormalizable Model*
ii) *Unification: O.K.*
iii) M_ν: *Type III and Type I seesaw, ONE massless neutrino*
iv) *Leptogenesis:* ρ_0, ρ_3 in 24
v) *Proton decay: O.K.*

Realistic

Supersymmetric

Grand Unified Theories

based on SU(5)

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SUSY SU(5) $\bigoplus$ R-parity Conservation

– Type I seesaw mechanism: $\hat{1}_i, i = 1, 2, ...$

– Type II seesaw mechanism: $\hat{15}_H \bigoplus \overline{\hat{15}}_H$

– Type III $\bigoplus$ Type I seesaw mechanisms: $\hat{24}$

Let us write a renormalizable SUSY SU(5) theory without singlets

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Supersymmetric Adjoint $SU(5)$

P. F. P., arXiv:0705.3589 [hep-ph].

Matter: $\hat{\bar{5}}_i = (\hat{D}_i^C, \hat{E}_i, \hat{N}_i)$, $\hat{10}_i = (\hat{U}_i^C, \hat{Q}_i, \hat{E}_i^C)$, $\hat{24}$

Higgs Sector: $\hat{5}_H$, $\hat{24}_H$, $\hat{45}_H$, $\hat{\bar{5}}_H$, $\overline{\hat{45}}_H$

$$\hat{24} = \underbrace{(8,1,0)}_{\hat{\rho}_8} \bigoplus \underbrace{(1,3,0)}_{\hat{\rho}_3} \bigoplus \underbrace{(3,2,-5/6)}_{\hat{\rho}_{(3,2)}} \bigoplus \underbrace{(\bar{3},2,5/6)}_{\hat{\rho}_{(\bar{3},2)}} \bigoplus \underbrace{(1,1,0)}_{\hat{\rho}_0}$$

$$\mathbf{\hat{45}_H} = (\hat{\Phi}_1, \hat{\Phi}_2, \hat{\Phi}_3, \hat{\Phi}_4, \hat{\Phi}_5, \hat{\Phi}_6, \hat{H}_2) = (8,2,1/2) \bigoplus (\overline{6},1,-1/3)$$
$$\bigoplus (3,3,-1/3) \bigoplus (\overline{3},2,-7/6) \bigoplus (3,1,-1/3) \bigoplus (\overline{3},1,4/3)$$
$$\bigoplus (1,2,1/2)$$

$$\overline{\mathbf{\hat{45}}}_{\mathbf{H}} = (\overline{\hat{\Phi}}_1, \overline{\hat{\Phi}}_2, \overline{\hat{\Phi}}_3, \overline{\hat{\Phi}}_4, \overline{\hat{\Phi}}_5, \overline{\hat{\Phi}}_6, \overline{\hat{H}}_2)$$

$(45)^{\alpha\beta}_{\delta} = -(45)^{\beta\alpha}_{\delta}, \qquad \sum_{\alpha=1}^{5} (45)^{\alpha\beta}_{\alpha} = 0,$

$v_{45} = \langle 45_H \rangle^{15}_{1} = \langle 45_H \rangle^{25}_{2} = \langle 45_H \rangle^{35}_{3},$

$v_{\overline{45}} = \langle \overline{45}_H \rangle^{1}_{15} = \langle \overline{45}_H \rangle^{2}_{25} = \langle \overline{45}_H \rangle^{3}_{35}.$

The Superpotential:

$$\mathcal{W}_0 = \hat{10}\ \hat{\bar{5}} \left(Y_1\ \hat{\bar{5}}_H \ + \ Y_2\ \hat{\overline{45}}_H \right) \ + \ \hat{10}\ \hat{10}\ \left(Y_3\ \hat{5}_H \ + \ Y_4\ \hat{45}_H \right)$$

$$\mathcal{W}_1 = c_i\ \hat{\bar{5}}_i\ \hat{24}\ \hat{5}_H \ + \ p_i\ \hat{\bar{5}}_i\ \hat{24}\ \hat{45}_H$$

$$\mathcal{W}_2 = m_\Sigma\, Tr\ \hat{24}^2_H + \lambda_\Sigma\, Tr\ \hat{24}^3_H + m\ Tr\ \hat{24}^2 \ + \ \lambda\ Tr\ (\hat{24}^2 \hat{24}_H)$$

$$\mathcal{W}_3 = m_H\ \hat{\bar{5}}_H \hat{5}_H \ + \ \lambda_H\ \hat{\bar{5}}_H \hat{24}_H \hat{5}_H \ + \ c_H\ \hat{\bar{5}}_H \hat{24}_H \hat{45}_H \ +$$

$$+ \ b_H\ \hat{\overline{45}}_H \hat{24}_H \hat{5}_H \ + \ m_{45}\ \hat{\overline{45}}_H \hat{45}_H \ + \ a_H\ \hat{\overline{45}}_H \hat{45}_H \hat{24}_H$$

RELATION BETWEEN CHARGED FERMION MASSES

$$\mathcal{W}_0 = \hat{10}\ \hat{\bar{5}}\ \left(Y_1\ \hat{\bar{5}}_H\ +\ Y_2\ \hat{\overline{45}}_H\right)\ +\ \hat{10}\ \hat{10}\ \left(Y_3\ \hat{5}_H\ +\ Y_4\ \hat{45}_H\right)$$

$$M_D = Y_1 v_{\bar{5}}\ +\ 2Y_2 v_{\overline{45}}\ ; \qquad M_E = Y_1^T v_{\bar{5}} - 6Y_2^T v_{\overline{45}}$$

NEUTRINO MASSES

$$\mathcal{W}_1 = c_i\ \hat{\bar{5}}_i\ \hat{24}\ \hat{5}_H\ +\ p_i\ \hat{\bar{5}}_i\ \hat{24}\ \hat{45}_H$$

$$\mathcal{W}_2 = m_\Sigma\ Tr\ \hat{24}_H^2 + \lambda_\Sigma\ Tr\ \hat{24}_H^3 + m\ Tr\ \hat{24}^2\ +\ \lambda\ Tr\ (\hat{24}^2 \hat{24}_H)$$

$$\hat{24} = \begin{pmatrix} \hat{\rho}_8 & \hat{\rho}_{(3,2)} \\ \hat{\rho}_{(\bar{3},2)} & \hat{\rho}_3 \end{pmatrix} + \frac{1}{2\sqrt{15}} \begin{pmatrix} 2 & 0 \\ 0 & -3 \end{pmatrix} \hat{\rho}_0$$

$$M^\nu_{ij} = a_i\ a_j\ M_{\rho_3}^{-1}\ +\ b_i\ b_j\ M_{\rho_0}^{-1}$$

$$a_i = c_i\ v_5\ -\ 3p_i\ v_{45} \qquad b_i = \frac{\sqrt{15}}{2}\left(\frac{c_i\ v_5}{5}\ +\ p_i\ v_{45}\right)$$

ONE massless neutrino !

Normal Neutrino Mass Hierarchy

$m_1 = 0$, $m_2 = \sqrt{\Delta m^2_{sun}}$ and $m_3 = \sqrt{\Delta m^2_{sun} + \Delta m^2_{atm}}$

Inverted Neutrino Mass Hierarchy:

$m_3 = 0$, $m_2 = \sqrt{\Delta m^2_{atm}}$ and $m_1 = \sqrt{\Delta m^2_{atm} - \Delta m^2_{sun}}$

$\Delta m^2_{sun} \approx 8 \times 10^{-5}$ eV^2 and $\Delta m^2_{atm} \approx 2.5 \times 10^{-3}$ eV^2

The relation between the masses of the fields in 24 is given by:

$$M_{\rho_8} = \frac{1}{2}\left(5M_{\rho_0} - 3M_{\rho_3}\right) \qquad M_{\rho_{(3,2)}} = \frac{1}{4}\left(5M_{\rho_0} - M_{\rho_3}\right)$$

Leptogenesis: ρ_0, ρ_3, $\tilde{\rho}_0$, and $\tilde{\rho}_3$ (Work in progress)

PROTON DECAY

– $d = 5$ contributions:

  * LLLL operators: $\left(\hat{Q}\ \hat{Q}\ \hat{Q}\ \hat{L}\right)/M_T^{eff}$

    mediated by $\tilde{T}$, $\tilde{\overline{T}}$, $\tilde{\Phi}_3$, $\tilde{\overline{\Phi}}_3$, $\tilde{\Phi}_5$, and $\tilde{\overline{\Phi}}_5$

  * RRRR operators $\left(\hat{U}^C\ \hat{E}^C\ \hat{U}^C\ \hat{D}^C\right)/M_T^{eff}$

    mediated by $\tilde{T}$, $\tilde{\overline{T}}$, $\tilde{\Phi}_5$, $\tilde{\overline{\Phi}}_5$, $\tilde{\Phi}_6$, and $\tilde{\overline{\Phi}}_6$.

– New $d = 5$ contributions

$\langle H \rangle \left(u d \tilde{d}^{C*} \tilde{\nu}\right)/M_T^2$

Work in progress !

For a review on proton decay see:
P. Nath, P. F. P., Phys. Rept. **441** (2007) 191 [arXiv:hep-ph/0601023].
See also: P. Nath and R. M. Syed, arXiv:0707.1332 [hep-ph]

SUMMARY and OUTLOOK

– *Supersymmetric Adjoint* $SU(5)$ (see arXiv:0705.3589 [hep-ph]) can be considered as the simplest renormalizable supersymmetric grand unified theory based on $SU(5)$ since it has the minimal number of superfields.

– If SUSY is not realized in nature the non-supersymmetric version of the model, *Renormalizable Adjoint* $SU(5)$ (see hep-ph/0702287), can be considered as an appealing candidate for the unification of SM gauge interactions.

– Both SUSY and Non-SUSY *Adjoint* $SU(5)$ models predict one-massless neutrino and the neutrino masses are generated through type I and type III seesaw mechanisms (Work in progress).

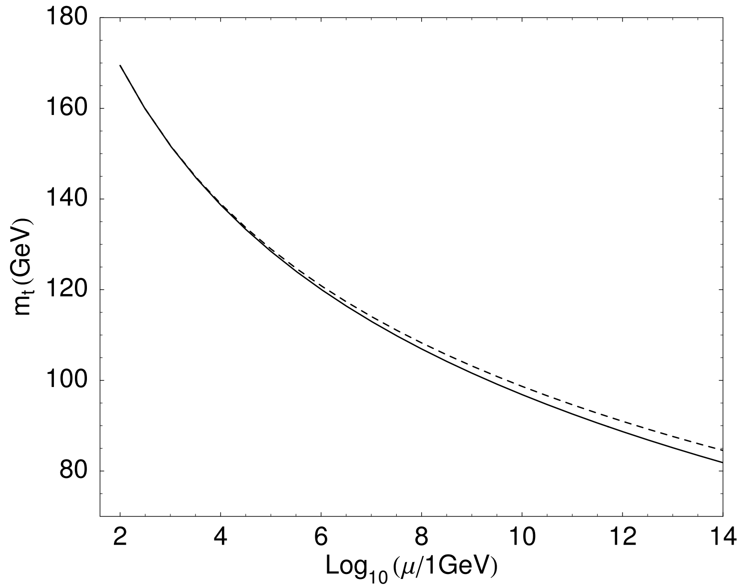
– In both models the Leptogenesis mechanism can be implemented. A net $B - L$ asymmetry can be generated in the Early Universe through the out of equilibrium decays of the fermions responsible for the seesaw mechanism and their superpartners in the adjoint matter chiral superfield (Work in progress).

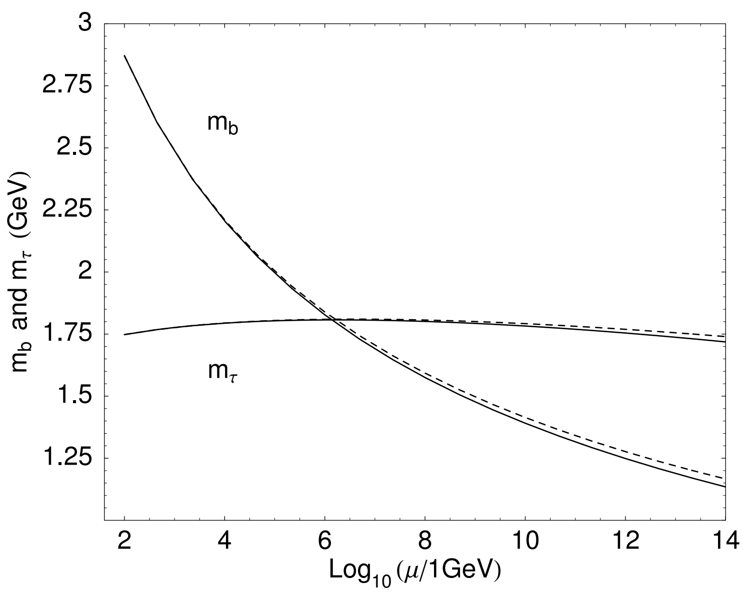
– There are new $d = 5$ contributions to proton decay (Work in progress).

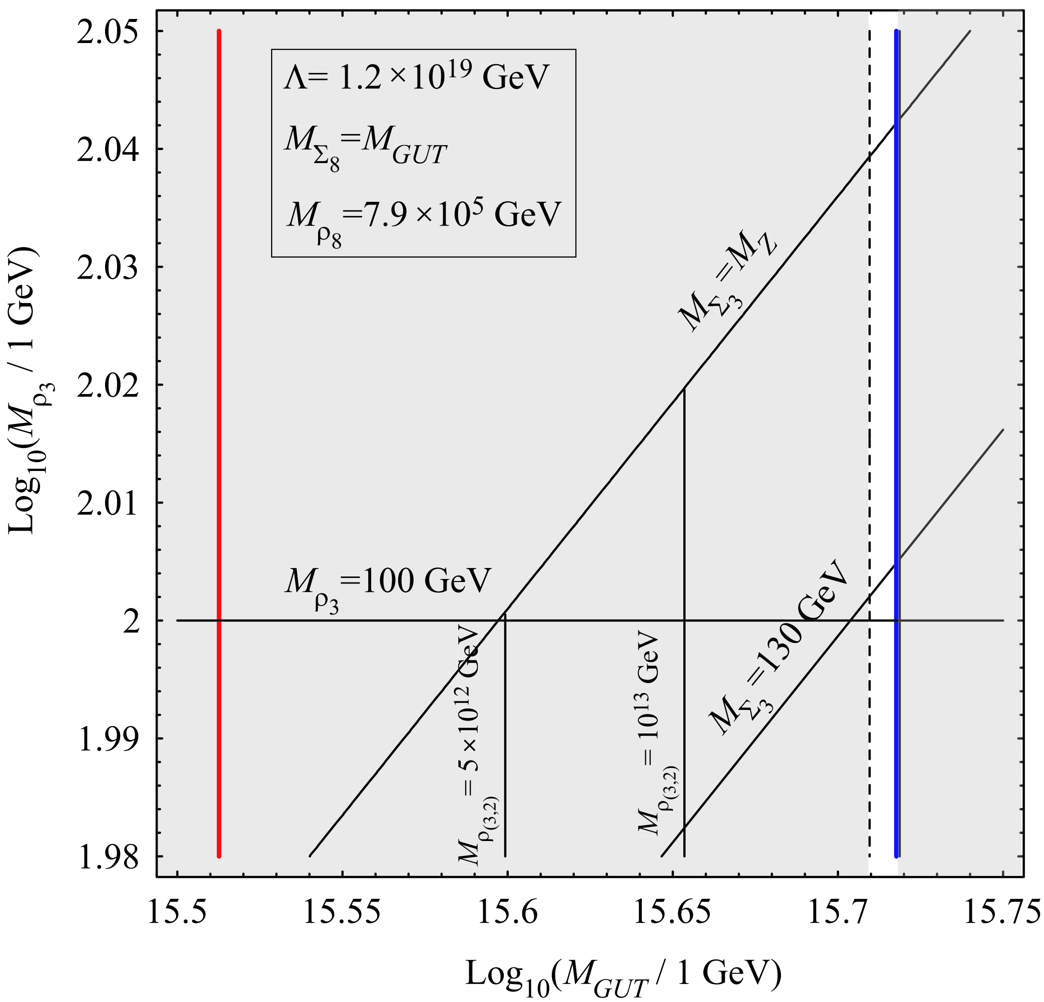
– The properties of the candidates for the Cold Dark Matter in the Universe, the neutralinos, will be discussed in detail (Work in progress).

Evolution of the fermion masses in the SM (Only third generation)

I. Dorsner, P.F.P, G. Rodrigo, Phys.Rev.D75:125007,2007






Λ= 1.2 ×10^19 GeV
M_Σ8 =M_GUT
M_ρ8 =7.9 ×10^5 GeV
M_Σ3 =M_Z
M_ρ3 =100 GeV
M_ρ(3,2) = 5 ×10^12 GeV
M_ρ(3,2) = 10^13 GeV
M_Σ3 =130 GeV
2.05
2.04
2.03
2.02
2.01
2
1.99
1.98
15.5
15.55
15.6
15.65
15.7
15.75
Log10(M_ρ3 / 1 GeV)
Log10(M_GUT / 1 GeV)