Vector like matter and grand unification

Borut Bajc

J. Stefan Institute, Ljubljana, Slovenia

Kaladi Babu, BB and Zurab Tavartkiladze, to appear

Outline

- The minimal susy SU(5)
- Mass constraint: problem and known solutions
- RGEs and proton decay: problems and known solutions
- New solution with vectorlike matter: the idea
- New solution with vectorlike matter: details
- Few thoughts on neutrino masses
- Conclusions

The minimal susy SU(5)

It is made of

- 3 generations of matter in $\bar{5}_i + 10_i$
- Higgses in 24_H and $5_H + \bar{5}_H$
- gauge superfield in 24_V

Mass constraint: the problem and known solutions

In minimal renormalizable susy SU(5) most general Yukawas

$$W_Y^{SU(5)} = Y_{10}^{ij} 10_i 10_j 5_H + Y_5^{ij} \bar{5}_i 10_j \bar{5}_H$$

$i, j = 1, \ldots 3$ (generation indices)

MSSM Yukawas parametrized by

$$W_Y^{MSSM} = Y_U^{ij} Q_i u_j^c H_u + Y_D^{ij} Q_i d_j^c H_d + Y_E^{ij} L e^c H_d$$

Easy to derive in our GUT that

$$BAD \quad \rightarrow \quad \begin{array}{rcll} M_U & = & M_U^T & (\propto Y_{10}) \\ M_D & = & M_E^T & (\propto Y_5) \end{array}$$

3^{rd} generation ($m_b = m_\tau$ at GUT scale) OK

1^{st} and 2^{nd} generation bad even after RGE's from GUT scale to EW scale

Well known solutions:

- add non-renormalizable ($1/M_{Planck}$) terms:

$$\frac{1}{M_{Planck}} Y^{ij} (\bar{5}_i)_\alpha (10_j)^{\alpha\beta} (24_H)^\gamma_\beta (\bar{5}_H)_\gamma$$

  $\alpha, \beta, \gamma = 1, \dots 5$ (SU(5) indices)

- extra Higgses: $45_H + \overline{45}_H$

In both cases accidental SU(4) of Yukawa terms after $\langle \bar{5}_H \rangle \neq 0$ broken

RGEs and proton decay: the problem and known solutions

From RGE's and known exp values of $\alpha_i(M_Z)$:

$$M_T \approx 10^{15}\text{GeV}\left(\frac{m_3}{m_8}\right)^{5/2}$$

$m_{3,8}\ldots$ masses of weak triplet and color octet in 24_H.

In minimal renormalizable susy SU(5):

$$m_3 = m_8 \to M_T \approx 10^{15}\text{GeV}$$

Color triplet T too light, mediates too fast proton decay!

$$W_T = Y_{10}^{ij}\left(Q_i Q_j + u_i^c e_j^c\right) T + Y_5^{ij}\left(u_i^c d_j^c + Q_i L_j\right)\bar{T}$$

Well known solutions:

- extra Higgs terms suppressed by $1/M_{Planck}$:
  If $24_H^4/M_{Planck} >> \lambda 24_H^3 \to m_3 = 4 m_8$
  and $M_T \approx 10^{16-17}$GeV
  Not enough yet, but much better.

- extra Yukawa terms suppressed by $1/M_{Planck}$:

$$\frac{1}{M_{Planck}} \left(10_i 10_j 24_H 5_H + 10_i \bar{5}_j 24_H \bar{5}_H + \ldots \right)$$

  $\to$ Yukawas in front of $T \neq$ Yukawas in front of H

- sfermion mixing can help, even make vanish the amplitude!

New solution with vectorlike matter: the idea

We look for solutions to both problems assuming renormalizable susy SU(5).

Just add an extra vectorlike matter multiplet $5_4 + \bar{5}_4$ with $M_{T_4}/M_{D_4} \approx 10^{-2}$

- will give $M_D \neq M_E^T$
- RGE solution will change into

$$M_T \approx 10^{15}\text{GeV} \left(\frac{m_3}{m_8}\right)^{5/2} \left(\frac{M_{D_4}}{M_{T_4}}\right)$$

In other words, it will be T_4 that will save unification, not T anymore. But T_4 does not mediate proton decay and thus can be lighter!

New solution with vectorlike matter: details

First, correction to masses

$$\bar{5}_a \left(\mu_a + \eta_a 24_H\right) 5_4 \qquad\qquad a = 1, \ldots 4$$

$$W_Y = \begin{pmatrix} \bar{5}_i & \bar{5}_4 \end{pmatrix} \begin{pmatrix} m_i^0 \delta_{ij} & M_i \\ 0 & M_4 \end{pmatrix} \begin{pmatrix} 10_j \\ 5_4 \end{pmatrix}$$

Find unitary matrix U such that

$$U \begin{pmatrix} M_i \\ M_4 \end{pmatrix} = \begin{pmatrix} 0 \\ \sqrt{M_i^2 + M_4^2} \end{pmatrix}$$

$$U = \begin{pmatrix} \Lambda & -\Lambda . x \\ \dots & \dots \end{pmatrix}$$

with

$$x_i = M_i / M_4 \qquad \Lambda_{ij} = \delta_{ij} - \frac{x_i x_j}{\sqrt{1+x^2}(\sqrt{1+x^2}+1)}$$

Then

$$\begin{pmatrix} \bar{5}_i & \bar{5}_4 \end{pmatrix} \to U \begin{pmatrix} \bar{5}_i & \bar{5}_4 \end{pmatrix}$$

so that

$$W_Y \to \begin{pmatrix} \bar{5}_i & \bar{5}_4 \end{pmatrix} \begin{pmatrix} \Lambda m^0 & 0 \\ \mathcal{O}(m^0) & M \end{pmatrix} \begin{pmatrix} 10_j \\ 5_4 \end{pmatrix}$$

Since

$$M_a = \mu_a + \eta_a \langle 24_H \rangle$$

breaks SU(5) we get

$$d^c \Lambda^d m^0 d + e \Lambda^e m^0 e^c$$

so that

$$M_D = \Lambda^d m^0 \qquad M_E = m^0 \Lambda^e$$

and one can successfully fit the masses

Second, p-decay

On top of the previous possible increase of T mass, other changes:

$$\frac{T}{v_u}\left(uPM_U^{diag}V_{CKM}d+u^cM_U^{diag}V_{CKM}V^\dagger e^c\right)$$
$$+\frac{\bar{T}}{v_d}\left(\nu M_E^{diag}Vd-eM_E^{diag}VV_{CKM}^\dagger u+d^cM_D^{diag}V_{CKM}^\dagger P^\dagger u^c\right)$$

P ... diagonal phase matrix (already in the minimal model)

V ... arbitrary unitary matrix (new)

One can further play with V to suppress some dangerous decay modes!

Two reasons why p-decay slow here:

- M_T can be larger that in the minimal SU(5)$\rightarrow M_{T_4}/M_{D_4} \approx 10^{-2}$
- freedom in V to cancel for example $p \rightarrow \bar{\nu} K^+$

Few thoughts on neutrino masses

- one can always add SU(5) singlets ν_R's, but obviously no prediction
- we have now terms $\eta_i \bar{5}_i 24_H 5_4$. Integrating heavy singlets S and weak triplets T in 24_H gives the Weinberg operator

$$\frac{\eta_i \eta_j}{M_{S,T}} \bar{5}_i 5_4 5_4 \bar{5}_j$$

But

1. only rank 1
2. masses $M_{S,T}$ too large
3. $\langle 5_4 \rangle = 0$ here

- This brings us to the possibility of R-parity violation

What we have here is in general

$$\begin{pmatrix} \bar{5}_i & \bar{5}_4 & \bar{5}_H \end{pmatrix} \begin{pmatrix} M_i & \mu_i \\ M_4 & \mu_4 \\ M_H & \mu_H \end{pmatrix} \begin{pmatrix} 5_4 \\ 5_H \end{pmatrix}$$

this mass matrix is different for doublets and triplets

1. for doublets:

$$\begin{pmatrix} M_i & M_4 & M_H \end{pmatrix} \propto \begin{pmatrix} \mu_i & \mu_4 & \mu_H \end{pmatrix}$$

   $\rightarrow$ 4 light weak doublets, 1 heavy weak doublet

2. for triplets:

   no particular relation so that

   $\rightarrow$ 3 light weak doublets, 2 heavy weak doublet

   but with mixing between heavy color tripelt $\bar{T}$ and MSSM d_i^c small enough (otherwise too large tree-level $d = 4$ p-decay):

$$U_{Hi} \lesssim \frac{M_{EW}}{M_{GUT}}$$

Fine-tuning obviously needed

- all this becomes harder and more constrained in SO(10):

1. $\nu_R \in 16$ already, $M^{\nu}_{Dirac} \approx M_{EW}$
2. give Majorana mass to ν_R

Work in progress.

Conclusions

- The renormalizable supersymmetric minimal SU(5) hard to reconcile with observations because of
  1. mass equality between charged leptons and down quarks
  2. light color triplet from unification $\rightarrow$ too fast proton decay
- we suggest to add extra heavy vectorlike $5_4 + \bar{5}_4$:
  1. mixing with light down quarks and charged leptons change their light mass matrix
  2. these extra color triplets can help unification, thus allowing color triplets that mediate proton decay to be heavier
- unexpected bonus: an extra arbitrary unitary matrix V in the Yukawas with color triplets further helps in suppressing p-decay
- ν masses can be obtained in a predictive fashion maybe only through R-parity breking couplings. Work still in progress.