Proton Stability in $SU(5) \times U(1)_X$ and $SU(6) \times SU(2)$ GUTs

(Faraggi,Paraskevas,Rizos,Tamvakis: 1405.2274 [hep-ph])

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GUTs - Motivations and problems.

Typical predictions of SUSY-GUT models are:

- Quantization of the electric charges, unification of gauge couplings (Grand Unification), partially successful mass relations for fermions (Yukawa Unification)...

but also problems among which:

- PROTON DECAY
- Technical difficulties for decoupling of Higgs states (SU(5)) or Matter states (non minimal GUTs)

Approach

- Suppression of dangerous D=6 Gauge mediated operators in explicit SUSY-GUT models by assigning standard matter in new representations - “Deunification"

- Decoupling of exotics, unavoidably introduced this way.

- Suppression of the other dangerous D=5,6 operators using suitable models.

Minimal flipped SU(5)- Review

Particle Content

$$\begin{aligned} \mathcal{F}_{(10,1)} &= (q, \nu^c, D^c) \\ \bar{f}_{(\bar{5},-3)} &= (L, u^c) \\ \ell^c_{(1,5)} &= e^c \end{aligned} \qquad \begin{aligned} \mathcal{H}_{(10,1)} &= (Q_H, N^c_H, D^c_H) \\ \overline{\mathcal{H}}_{(\overline{10},-1)} &= (\overline{Q}_H, \overline{N}^c_H, \overline{D}^c_H) \\ h_{(5,-2)} &= (h_d, \overline{\delta}^c_h) \\ \overline{h}_{(\bar{5},2)} &= (h_u, \delta^c_h)\,. \end{aligned}$$

Minimal Superpotential (no Neutrinos)

$$\mathcal{W} = \mathcal{Y}_u \mathcal{F} \bar{f} \bar{h} + \mathcal{Y}_d \mathcal{F}\mathcal{F} h + \mathcal{Y}_e \bar{f} \ell^c h + \lambda\, h\mathcal{H}\mathcal{H} + \overline{\lambda}\, \overline{h\mathcal{H}\mathcal{H}}$$

$$SU(5) \times U(1)_X \xrightarrow{\langle N^c_H \rangle = \langle \overline{N}^c_H \rangle \neq 0} SU(3)_C \times SU(2)_L \times U(1)_Y$$

$$\lambda\, \mathcal{H}\mathcal{H}h + \overline{\lambda}\, \overline{\mathcal{H}}\, \overline{\mathcal{H}}\, \overline{h} \supset \lambda \langle N^c_H \rangle\, D^c_H\, \overline{\delta}^c_h + \overline{\lambda}\, \langle \overline{N}^c_H \rangle \overline{D}^c_H\, \delta^c_h$$

- Natural doublet-triplet splitting (Missing Partner).
- Matter sector: $Y_u^\top = Y_\nu^D \neq Y_d \neq Y_e$

Proton Decay

Relevant terms in the superpotential:

$$\mathcal{F}\mathcal{F}h \supset qq\overline{\delta}_h^c\,,\ \ \mathcal{F}\overline{f}\overline{h} \supset qL\delta_h^c\,,\ \ \overline{f}\ell^c h \supset e^c u^c \overline{\delta}_h^c$$

- D=5 operators typically disastrous but here heavily suppressed essentially due to the MP mechanism.

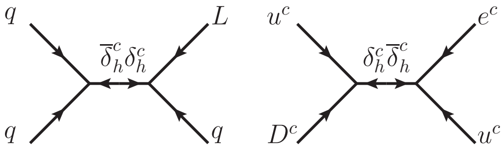

Figure: *The formation of dangerous D=5 operators would require a chirality flip (order M_G mass mixing for the bilinear $\overline{\delta}_h^c\delta_h^c$). This is not provided by the theory.*

- A scalar mediated $D = 6$ operator is present at tree level (i.e.$(qq)(e^{c\dagger}u^{c\dagger})$) but smaller than...

Flipping away Proton Decay

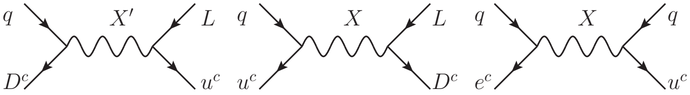

Figure: *Gauge mediated decay through the exchange of* $X'(3,2,1/6)$ *in flipped or* $X(3,2,-5/6)$ *in standard* $SU(5)$.

- Gauge mediated $D = 6$ present at tree level

$$\mathcal{F}^{\dagger}\mathbf{V}\mathcal{F} \supset D^{c\dagger}X'q\,,\ \ \bar{f}^{\dagger}\mathbf{V}\bar{f} \supset u^{c\dagger}\overline{X'}L \ \longrightarrow \frac{(D^{c\dagger}q)(u^{c\dagger}L)}{M_{X'}}$$

What if $D^c \notin \mathcal{F}$ and/or $L \notin \bar{f}$?
Standard matter in new extra irreps - "Deunification" . (*Dimopoulos&Hall,1985 - General Criteria*)

- The tree level gauge mediated operators would be absent.
- **Model independent** approach - Matter Representation dependent

“Deunifying” the Flipped

Extended Flipped SU(5)-I

Particle Content

$$\begin{aligned} \mathcal{F}_{(10,1)} &= (q, \nu^c, D'^c) \\ \bar{f}_{(\bar{5},-3)} &= (L', u^c) \\ \ell^c_{(1,5)} &= e^c \\ \mathcal{G}_{(5,-2)} &= (L, \overline{D'}^c) \\ \overline{\mathcal{G}}_{(\bar{5},2)} &= (\overline{L}', D^c) \end{aligned}$$

$$\begin{aligned} \mathcal{H}_{(10,1)} &= (Q_H, N^c_H, D^c_H) \\ \overline{\mathcal{H}}_{(\overline{10},-1)} &= (\overline{Q}_H, \overline{N}^c_H, \overline{D}^c_H) \\ h_{(5,-2)} &= (h_d, \overline{\delta}^c_h) \\ \overline{h}_{(\bar{5},2)} &= (h_u, \delta^c_h)\,. \end{aligned}$$

$\mathcal{Z}_4^{(R)}$ charges

$$\begin{aligned} \mathcal{F},\, \mathcal{G} &\to 3 \\ h,\, \overline{h} &\to 2 \\ \bar{f},\, \ell^c,\, \overline{\mathcal{G}} &\to 1 \\ \mathcal{H},\, \overline{\mathcal{H}} &\to 0\,. \end{aligned}$$

Superpotential

$$\begin{aligned} \mathcal{W}_R \quad = \quad & \mathcal{Y}_u \mathcal{F}\bar{f}\,\overline{h} + \mathcal{Y}_D \mathcal{F}\,\mathcal{G}\mathcal{H} + \mathcal{Y}_L \bar{f}\,\overline{\mathcal{G}}\mathcal{H} + \lambda\,\mathcal{H}\mathcal{H}h + \overline{\lambda}\,\overline{\mathcal{H}}\,\overline{\mathcal{H}}\,\overline{h} \\ & + \frac{\mathcal{Y}'_d}{M}\mathcal{F}\,\overline{\mathcal{G}}h\overline{\mathcal{H}} + \frac{\mathcal{Y}'_e}{M}\mathcal{G}\ell^c h\overline{\mathcal{H}} \end{aligned}$$

invariant under an $\mathcal{Z}_4^{(R)}$ symmetry .

- Standard symmetry breaking pattern (MP mechanism)

$$SU(5)\times U(1)_X \xrightarrow{\langle N^c_H\rangle = \langle \overline{N}^c_H\rangle \neq 0} SU(3)_C \times SU(2)_L \times U(1)_Y$$

$$\lambda\,\mathcal{H}\mathcal{H}h + \overline{\lambda}\,\overline{\mathcal{H}}\,\overline{\mathcal{H}}\,\overline{h} \supset \lambda \langle N^c_H\rangle\, D^c_H\, \overline{\delta}^c_h + \overline{\lambda}\,\langle \overline{N}^c_H\rangle \overline{D}^c_H\, \delta^c_h$$

Extended Flipped SU(5) - II

$$\begin{aligned} \mathcal{F}_{(10,1)} &= (q, \nu^c, D'^c) \\ \bar{f}_{(\bar{5},-3)} &= (L', u^c) \\ \ell^c_{(1,5)} &= e^c \\ \mathcal{G}_{(5,-2)} &= (L, \overline{D'}^c) \\ \overline{\mathcal{G}}_{(\bar{5},2)} &= (\overline{L}', D^c) \end{aligned}$$

$$\begin{aligned} \mathcal{H}_{(10,1)} &= (Q_H, N^c_H, D^c_H) \\ \overline{\mathcal{H}}_{(\overline{10},-1)} &= (\overline{Q}_H, \overline{N}^c_H, \overline{D}^c_H) \\ h_{(5,-2)} &= (h_d, \overline{\delta}^c_h) \\ \overline{h}_{(\bar{5},2)} &= (h_u, \delta^c_h)\,. \end{aligned}$$

$\mathcal{Z}_4^{(R)}$ charges

$$\begin{aligned} \mathcal{F},\, \mathcal{G} &\to 3 \\ h,\, \overline{h} &\to 2 \\ \bar{f},\, \ell^c,\, \overline{\mathcal{G}} &\to 1 \\ \mathcal{H},\, \overline{\mathcal{H}} &\to 0 \end{aligned}$$

- Decoupling of extra matter

$$\mathcal{Y}_D\, \mathcal{F}\, \mathcal{G}\mathcal{H} + \mathcal{Y}_L \bar{f}\, \overline{\mathcal{G}}\mathcal{H} \supset \mathcal{Y}_D \langle N^c_H \rangle D'^c \overline{D'}^c + \mathcal{Y}_L \langle N^c_H \rangle L' \overline{L'}$$

- EW masses for charged fermions (small $\tan\beta$)

$$\mathcal{Y}_u\, \mathcal{F}\bar{f}\,\overline{h} + \frac{\mathcal{Y}'_d}{M}\mathcal{F}\,\overline{\mathcal{G}}h\overline{\mathcal{H}} + \frac{\mathcal{Y}'_e}{M}\mathcal{G}\ell^c h\overline{\mathcal{H}} \supset \mathcal{Y}_u\, q u^c h_u + \frac{\mathcal{Y}'_d \langle \overline{N}^c_H \rangle}{M} q D^c h_d + \frac{\mathcal{Y}'_e \langle \overline{N}^c_H \rangle}{M} L e^c h_d$$

- Proton Decay?

Extended Flipped SU(5) - III

Proton Decay.

The D=6 gauge mediated operators are absent at tree level

$$\mathcal{F}^\dagger \mathbf{V} \mathcal{F} \supset ({D'^c}^\dagger q)\, X' \ , \ \ \overline{f}^\dagger \mathbf{V} \overline{f} \supset ({u^c}^\dagger L')\, \overline{X'} \ ,$$

$$\mathcal{G}^\dagger \mathbf{V} \mathcal{G} \supset ({\overline{D'}^c}^\dagger L)\, X' \ , \ \ \overline{\mathcal{G}}^\dagger \mathbf{V} \overline{\mathcal{G}} \supset ({D^c}^\dagger \overline{L'})\, \overline{X'}$$

since always heavy matter (primed fields) included.

- Gauge mediated operators are essentially related to the decoupling mechanism of heavy matter. If we allowed small mass mixing ($\mu \overline{\mathcal{G}} \mathcal{G}$) with light matter

  $$\mu\, \overline{D'}^c D^c + M_G\, \overline{D'}^c D'^c$$

  the relevant operators would be suppressed accordingly

  $$D'^c \approx \left(\frac{\mu}{M_G}\right) d^c + \mathcal{D}^c$$

  while the light mass spectrum would receive seesaw-type contributions ($\mu^2\,/M_G$).

Extended Flipped SU(5) - IV

Proton Decay.
For the other D=5,6 operators the relevant terms in the superpotential read

$$\mathcal{Y}_u \mathcal{F}\bar{f}\,\bar{h} + \mathcal{Y}_D \mathcal{F}\mathcal{G}\mathcal{H} + \mathcal{Y}_L \overline{f\mathcal{G}}\mathcal{H} \quad \supset \quad \mathcal{Y}_u \left(D'^c u^c \delta_h^c + qL' \delta_h^c \right) + \mathcal{Y}_D \left(q\,L\,D_H^c \right) \\ \mathcal{Y}_L \left(u^c\,D^c\,D_H^c \right)$$

- The $D = 6$ scalar mediated operator $qL(u^c D^c)^\dagger$ appears at tree level but it is controlled through $\mathcal{Y}_D \mathcal{Y}_L$, relevant only to heavy matter.
- The $D = 5$ operators cannot form since there is no chirality flip available. In addition, the unbroken $\mathcal{Z}_4^{(R)}$ symmetry protects the theory since

$$qqqL \subset \mathcal{F}\mathcal{F}\mathcal{F}\mathcal{G} \quad , \quad u^c u^c D^c e^c \subset \overline{ff\mathcal{G}}\ell^c$$
$$\mathcal{Q}^{(R)}_{\mathcal{F}\mathcal{F}\mathcal{F}\mathcal{G}} = 12 \quad , \qquad \mathcal{Q}^{(R)}_{\overline{ff\mathcal{G}}\ell^c} = 4$$
$$\neq 2 \mod 4$$

Deunification in $SU(6) \times SU(2)_R$

An $\mathrm{SU}(6) \times \mathrm{SU}(2)_{\mathrm{R}}$ model - I

Particle Content

$$\Psi_{(15,1)} = (\mathcal{F},\mathcal{G}) \supset (q,L) \qquad \Phi_{(15,1)} = (\mathcal{H}, h_1) \qquad \phi_{(\overline{6},2)} = (\ell^c_H, \overline{f}_H, N_H, \overline{h}_2)$$

$$\psi_{(\overline{6},2)} = (\ell^c, \overline{f}, N, \overline{\mathcal{G}}) \supset (e^c, u^c, D^c) \qquad \overline{\Phi}_{(\overline{15},1)} = (\overline{\mathcal{H}}, \overline{h}_1) \qquad \overline{\phi}_{(6,2)} = (\overline{\ell}^c_H, f_H, \overline{N}_H, h_2),$$

Superpotential

$$\mathcal{W} = \mathcal{Y}_D\, \Psi\Psi\Phi + \mathcal{Y}_L\, \psi\psi\Phi + \lambda_1 \overline{\Phi}^3 + \lambda_2\, \phi^2\Phi + \frac{\lambda'}{M}\Phi^2\overline{\phi}^2 + \frac{\mathcal{Y}}{M}\Psi\psi\overline{\phi}\,\overline{\Phi}$$

Symmetry Breaking

$$SU(6)\times SU(2)_R \xrightarrow{\langle N_H,\overline{N}_H\rangle} SU(5)\times U(1)_X \xrightarrow{\langle N^c_H,\overline{N}^c_H\rangle} SU(3)_C\times SU(2)_L\times U(1)_Y$$

$$\lambda_1 \overline{\mathcal{H}}^2\overline{h}_1 + \lambda_2\,\langle N_H\rangle \overline{h}_2 h_1 + \frac{\lambda'}{M}\langle \overline{N}_H\rangle \mathcal{H}^2 h_2$$

- Light Higgs doublets in $\overline{h}_1, h_2$ - No remnants for Higgs!
- The $\mathcal{Y}_D, \mathcal{Y}_L$ terms induce decoupling of extra matter as in flipped - No remnants for matter!

An $\mathrm{SU}(6) \times \mathrm{SU}(2)_{\mathrm{R}}$ model - II

Proton Decay

- For the $D = 6$ gauge mediated operators the "deunification" manifests as

$$(q, L) \in \Psi_{(15,1)} \qquad (e^c, u^c, D^c) \in \psi_{(\overline{6},2)}$$

and therefore the only bilinears that can form at tree level are

$$(q\, L^\dagger)\ ,\ (D^{c\,\dagger} u^c)\ ,\ (D^{c\,\dagger} e^c)\ \ (u^{c\,\dagger} e^c)\ ,\ h.c.$$

However, gauge symmetry forbids the dangerous operators.

For the other dangerous operators

$$\mathcal{Y}_D\ \Psi\Psi\Phi + \mathcal{Y}_L\, \psi\psi\Phi + \frac{\mathcal{Y}}{M}\Psi\psi\overline{\phi}\,\overline{\Phi} \quad \supset \quad \mathcal{Y}_D(\, qLD^c_H + qq\,\overline{\delta}^c_{h_1}) + \mathcal{Y}_L(\, u^c D^c D^c_H + u^c e^c \overline{\delta}^c_{h_1})$$

$$+\, \mathcal{Y}\frac{\langle \overline{N}_H \rangle}{M}\left(D'^c u^c \delta^c_{h_1} + qL' \delta^c_{h_1}\right)$$

- The scalar D=6 operators are present but controllable from $\mathcal{Y}_D\mathcal{Y}_L$ as in flipped.
- The D=5 operators are heavily suppressed due to an extended MP mechanism. (i.e. only $\overline{\delta}^c_{h_1}\delta^c_{h_2}$, $\overline{\delta}^c_{h_2}D^c_H$, $\overline{D}^c_H\delta^c_{h_1}$ mass terms present. No other $\mathcal{O}(M_G)$ mixing!)

Conclusions

Features

- No exotic remnants in the MSSM spectrum.
- The gauge mediated D=6 operators are absent/suppressed at tree level due to "deunification" of matter fields.
- The scalar mediated D=6 operators are present but controlled by couplings irrelevant with light matter.
- The D=5 operators are heavily suppressed (MP).
- Analogous approach on other GUTs i.e. $SU(6) \times SU(2)_L$

Perspectives

- Escape to non-susy GUTs (Flipped SU(5) *(Barr,Calmet)*)
- Insight for an analogous approach to other susy-GUTs.
- Another future escape for minimal flipped (susy).
  $p \to e^+ + \pi^0$.
  Flipped: 10^{34}-$10^{35(36)}$ **. VS .** *Hyper-K*: 2×10^{35} (yrs)

(Faraggi,Paraskevas,Rizos,Tamvakis - Arxiv: 1405.2274 [hep-ph])

Back-up $SU(6) \times SU(2)_R$

Matter

$$
\begin{aligned}
\Psi\Psi\Phi &= \mathcal{F}\mathcal{G}\mathcal{H} + \mathcal{F}^2 h_1 \\
\psi\psi\Phi &= \bar{f}\bar{\mathcal{G}}\mathcal{H} + \bar{f}\ell^c h_1 + \bar{\mathcal{G}} N h_1 \\
\Psi\psi\bar{\phi}\,\bar{\Phi} &= \mathcal{G}\bar{\mathcal{G}} h_2 \bar{h}_1 + \mathcal{F}\bar{f}\bar{N}_H \bar{h}_1 + \mathcal{G}\ell^c h_2 \bar{\mathcal{H}} + \mathcal{F}\bar{\mathcal{G}} h_2 \bar{\mathcal{H}} \\
&\quad + \mathcal{G} N \bar{N}_H \bar{h}_1 + \mathcal{F} N \bar{N}_H \bar{\mathcal{H}}\,.
\end{aligned}
$$

Decoupling a la flipped $\mu\bar{\mathcal{G}}\mathcal{G} + M_G\mathcal{F}\mathcal{G} + M_G\bar{f}\bar{\mathcal{G}}$

$$
\mu \equiv \mathcal{Y}\frac{v_u v_d}{M} \ll \mathcal{Y}_L\langle N_H\rangle \sim \mathcal{Y}_D\langle N_H\rangle \equiv M_G\,, \tag{1}
$$

- Tiny mixing ($\sim \mu/M_G$) between $D^c - D'^c$ and $L - L'$ but not problematic. No remnants for matter!

$$
Z_{10}^{(R)} \times Z_2
$$

$$
\begin{aligned}
&\Psi \to (6,1)\,, \qquad \Phi \to (0,0)\,, \qquad \bar{\Phi} \to (4,0) \\
&\psi \to (1,1)\,, \qquad \phi \to (6,0)\,, \qquad \bar{\phi} \to (1,0)\,.
\end{aligned}
$$