Neutrino masses in Supersymmetric $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ models

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331 models

Motivations

- At low energies they coincide with the SM
- It requires three generations to cancel triangle anomalies
- It treats the third generation differently than the first two, this lead to an explanation of the heavy top quark mass.
- The model predicts that there is a Landau pole at the scale μ at wich $\sin^2\theta_W(\mu) = 1/4$, and some recent calculations indicate that $\mu \sim 4$ TeV.
- The model has an automatic Peccei-Quinn symmetry
- There are several models, distinguished by the embedding of the charge operator into the $SU(3)_L$ group and by the choice of fermion representations.

331 models

- The minimal version of the model by Frampton and Pisano,
- the charged leptons and neutrinos are put into antitriplets of $SU(3)_L$,
- Two generations of left-handed quarks are put into triplets and the other generation into an antitriplet.
- This structure automatically cancels all anomalies
- Combined with the requirement of asymptotic freedom $\longrightarrow$ the number of generations is equal to three.
- It contains doubly charged bilepton gauge fields, as well as isosinglet quarks with exotic charges, leading to a rich phenomenology
- Finally, there is an *upper* bound on the scale of $SU(3)_L$ breaking which is within range of the LHC.

331 models

- A simple alternative to this model is to change the lepton structure by replacing the standard model conjugate leptons, e_i^c with heavy leptons E_i^+ and adding e_i^c and E_i^- singlets.
- In another version of the model, with a different embedding of the charge operator into $SU(3)_L \times U(1)$, the charged lepton in the antitriplet is replaced by a right-handed neutrino. In this version, the bileptons are singly charged or neutral
- Another model, can be found in which there are no lepton-number violating gauge bosons and no exotic quark charges (at the price of adding an isosinglet charged lepton for each generation)

Classification

- The classification of 331 models without any exotic charges assigned is given by the embedding of the charge operator into the $SU(3)_L$ group and by the choice of fermion representations.
- Some 331 models cancel out the anomalies inside the femionic generation and others treat different each generation and cancell all the anomalies requiering the three generations

The most general expression for the electric charge generator in $SU(3)_L \otimes U(1)_X$ is

$$Q = aT_{3L} + \frac{2}{\sqrt{3}} bT_{8L} + xI_3, \tag{1}$$

Our First 331 model

The first 331 model considered has the following structure:

- $Q_1(3^*, \frac{1}{3}) = (d_1, u_1, U_1)$, $d_1(1, \frac{1}{3})$, $u_1(1, -\frac{2}{3})$, $U_1(1, -\frac{2}{3})$,
- $Q_i(3, 0) = (u_i, d_i, D_i)$, $u_i(1, -\frac{2}{3})$, $d_i(1, \frac{1}{3})$ y $D_i(1, \frac{1}{3})$

Then, the lepton families are assigned to:

- $L_1(3, -\frac{2}{3}) = \left(\nu_i, e_i^-, E_i^-\right)$, $L_2 = (3 - \frac{1}{3})\left(e_i^-, \nu_i, N_i^0, \right)$
- $L_3(3, -1/3) = \left(e_i^-, \nu_i, N_1^0\right)$, $L_4(3, -1/3) = \left(E_i^-, N_2^0, N_3^0\right)$,
- $L_5(3^*, 2/3) = \left(N_4^0, E_i^+, e_i^+\right)$, with $e_i^+(1, 1)$,$e_i^+(1, 1)$, $E_i^+(1, 1)$

Second model based on 331 gauge symetry

Another kind of 331 model can be build up using:

- $Q_1(3,0) = (u_1, d_1, D_1)$,
- $u_i(1, -\frac{2}{3})$, $d_i(1, \frac{1}{3})$, $D_i(1, \frac{1}{3})$,
- $Q_i(3^*, \frac{1}{3}) = (d_i, u_i, U_i)$, $d_i(1, \frac{1}{3})$, $u_i(1, -\frac{2}{3})$, $U_i(1, -\frac{2}{3})$

And for the leptons :

- $L_1(3, -\frac{2}{3}) = \left(\nu_i, e_i^-, E_i^-\right)$, $L_2(3, -\frac{1}{3}) = \left(e_i^-, \nu_i, N_i^0\right)$,
- $L_3(3, -\frac{2}{3}) = \left(\nu_i, e_i^-, E_{1i}^-\right)$, $L_4(3, \frac{1}{3}) = \left(E_{2i}^-, N_1^0, N_2^0\right)$,
- $L_5(3^*, -\frac{2}{3}) = \left(N_3^0, E_{2i}^-, E_{3i}^-\right)$ con $e_i^+(1,1)$, $E_i^+(1,1)$, where $i = e, \mu, \tau$.

Now, SUSY versions

Now for the supersymmetric version, the most general superpotential can be written as

$$
\begin{aligned}
W = {} & h^{u}_{ia}\hat{Q}^{ua}_{i}\hat{L}_4 + h^{U}_{i}\hat{Q}^{U}_{i}\hat{L}_4 + h^{d}_{iab}\hat{Q}_i\hat{d}_a\hat{L}_b + h^{D}_{ija}\hat{Q}_i\hat{D}_i\hat{L}_a \qquad (2) \\
& + h^{d\prime}_{a}\hat{Q}_1\hat{d}_a\hat{L}_5 + h^{\prime D}_{i}\hat{Q}_1\hat{D}_i\hat{L}_5 + h^{e}_{ab}\hat{L}_a\hat{e}_b\hat{L}_5 + \frac{1}{2}\lambda_{ab}\hat{L}_a\hat{L}_b\hat{L}_4 \\
& + \mu\hat{L}_4\hat{L}_5 + \lambda^{1}_{abi}\hat{u}_a\hat{d}_b\hat{D}_i + \lambda^{2}_{ai}\hat{U}\hat{d}_a\hat{D}_i + \lambda^{3}_{ijk}\hat{Q}_i\hat{Q}_j\hat{Q}_k \\
& + \lambda^{4}_{abc}\hat{u}_a\hat{d}_b\hat{d}_c + \lambda^{5}_{aij}\hat{u}_a\hat{D}_i\hat{D}_j + \lambda^{6}_{ab}\hat{U}\hat{d}_a\hat{d}_b\lambda^{7}_{ij}\hat{U}\hat{D}_i\hat{D}_j
\end{aligned}
$$

Symmetry Breaking

The SUSY versions can be constructed with the scalar and the lepton fields acting as superpartners of each other, and therefore a SUSY model without Higgsinos, which is automatically free of quiral anomalies. The symmetry is broken in two steps

$$\begin{aligned} SU(3)_c \otimes SU(3)_L \otimes U(1)_Y &\rightarrow SU(3)_c \otimes SU(2)_L \otimes U(1)_Y (3) \\ &\rightarrow SU(3)_c \otimes U(1)_Q . \end{aligned}$$

with the vacuum expectation values V for the first break, and v for the second step. And Supersymmetry is broken adding the soft terms Lagrangian.

Neutralino mass matrices

In the framework of this 331 model, 8 neutral fermionic particles and 5 neutral gauginos are identified, then the basis became

$$(\nu_e,\ \nu_\mu,\ \nu_\tau,\ N_e,\ N_\mu,\ N_\tau,\ N_4,\ N_5,\ \widetilde{B^0},\ \widetilde{A_3},\ \widetilde{A_8},\ \widetilde{K^0},\widetilde{\bar{K}_0}),$$

and the neutralino matrix has the following composition:

$$M_{neutralinos} = \begin{pmatrix} M_N|_{8x8} & M_{gN}^T|_{8x5} \\ M_{gN}|_{5x8} & M_g|_{5x5} \end{pmatrix}$$

- $(M_N)_{ij}$ are $M_{16} = M_{61} = -M_{34} = -M_{43} = \lambda v/2$, $M_{17} = M_{71} = \lambda V/2$ and $M_{78} = M_{87} = \mu/2$.
- M_{gN} are $M_{43} = -g_3 V$, $M_{61} = -g_1 V$, $M_{63} = 2g_3 V$, $M_{71} = -g_1 v$, $M_{72} = g_3 v$ and $M_{73} = -g_3 v$.
- $M_g = diag(M_1, M_2, M_2, M_2 A_2)$

Neutralino mass matrices

For the second 331 model shown before there are 7 neutral fermionic particles and 5 neutral gauginos. So, the basis used is

$$(\nu_e,\ \nu_\mu,\ \nu_\tau,\ N_4,\ N_5,\ N_6,\ N_7,\ \widetilde{B^0},\ \widetilde{A_3},\ \widetilde{A_8},\ \widetilde{K^0},\widetilde{\bar{K}_0})$$

and in this basis the matrix is written as

$$M_{neutralinos} = \begin{pmatrix} M_N|_{7x7} & M_{gN}^T|_{7x5} \\ M_{gN}|_{5x7} & M_g|_{5x5} \end{pmatrix} \quad (4)$$

- M_N is $M_{14} = M_{15} = M_{41} = M_{51} = \lambda V/2$ y $M_{64} = M_{46} = M57 = M_{75} = \mu/2$.
- For M_{gN} : $M_{53} = -g_3 v,\ M_{41} = -M_{61} = 2\sqrt{2}g_1 v/3$, $M_{51} = -M_{71} = 2\sqrt{2}g_1 V/3$ and $M_{35} = -M_{37} = -g_3\sqrt{2}V/2$

Neutrino oscillation data

Considere that the neutrinos with a well established mass are: ν_1, ν_2, ν_3 wiht masses m_1, m_2, m_3. These states are the mass eigenstates and they are related with the flavor eigenstates $(\nu_e, \nu_\mu, \nu_\tau)$. The two basis are related through an unitary matrix U, $\nu_\alpha = U_{\alpha i}\nu_i, \qquad \alpha = e, \mu, \tau, \qquad i = 1, 2, 3$. The mixing matrix $U_{\alpha i}$ can be parameterized using rotation matrices and extra complex phases as,

$$U_{PMNS} = V_{23}(\theta_{23}) I_{-\delta} V_{13}(\theta_{13}) I_\delta V_{12}(\theta_{12}), \tag{5}$$

where V_{ij} are the rotation matrices over a plane ij and θ_{ij} is the angle and the phase violation matrix CP $I_\delta \equiv diag(1, 1, , e^{i\delta})$.

Neutrino oscillation data

A summary of the constraints imposed by neutrino oscillation data to the neutrino mass diferences and mixing angles,

$$\sin^2 2\theta_{13} = 0 \pm 0.05 \qquad \Delta m_{12}^2 = (8.0 \pm 0.3)10^{-5} eV^2$$

$$\tan^2 \theta_{12} = 0.45 \pm 0.05$$

$$|\Delta m_{23}^2| = (2.5 \pm 0.2)10^{-3} eV^2 \qquad \sin^2 2\theta_{23} = 1.02 \pm 0.04$$

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Conclusions

The diagonalization of the mass matrix was done numerically. Covering a wide range of the parameters involved in the mass mastrix in such a way that the masses gotten for the neutrinos obey the experimental constraints $\Delta m^2_{12} = (8.0 \pm 0.3)10^{-5} eV^2$ and $\Delta m^2_{23} = (2.5 \pm 0.2) eV^2$, the results are

Model	$\Delta m^2_{12}(eV^2)$	$\Delta m^2_{23}(eV^2)$	λ	μ	v	V
1	8.11	2.4	10^{-9}	10	0.5	2
2	7.93	2.3	10^{-9}	20	0.1-1	3

Conclusions

- Supersymmetric versions of two different 331 models where presented.
- The superpotential has the same structure for both models.
- The neutralino mass matrix was calculated in each model considered.
- The neutrino sector of the models mixes with neutral superpartners and therefore the neutrinos get masses once the diagonalization of the neutralino mass matrix is performed.

Thank you