The Annual Seminar Phenomenological Study of the Standard-Like Heterotic String Models

Johar M. Ashfaque

University of Liverpool

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Introduction

I will present some results on the computation of the Higgs boson mass matrices based on the Standard-Like heterotic string models. I will finish off by mentioning some of the work that still needs to be done, mainly the computation of the RGEs.

Reference(s)

Light Z' in Heterotic String Standard-like Models,
Phys.Rev. D89 (2014),
P. Athanasopoulos, A.E. Faraggi, and V.M. Mehta.

Phenomenological Aspects of E_6 Superstring-Inspired Models,
Int.J.Mod.Phys. A3 (1988),
F. Zwirner.

Charges for the fields from the paper by A. Faraggi et al.

Field	$U(1)_{C''}$	$U(1)_{4'}$	$U(1)_{\zeta'}$
Q_L^i	$+\frac{1}{2}$	0	$+\frac{1}{2}$
u_L^i	$-\frac{1}{2}$	-1	$+\frac{1}{2}$
d_L^i	$-\frac{1}{2}$	$+1$	$+\frac{1}{2}$
e_L^i	$+\frac{3}{2}$	$+1$	$+\frac{1}{2}$
L_L^i	$-\frac{3}{2}$	0	$+\frac{1}{2}$
n_L^i	$+\frac{3}{2}$	-1	$+\frac{1}{2}$
D^i	-1	0	-1
$\overline{D}^i$	$+1$	0	-1
H_1^i	0	$+1$	-1
H_2^i	0	-1	-1
N^i	0	0	$+2$

Superpotential a la AVP

$$\begin{aligned}
\mathcal{W} \quad = \quad & QuH_2 + QdH_1 + LeH_1 + LnH_2 \\
& + H_1 H_2 N + D\overline{D}N \\
& + QQD + ud\overline{D} + dnD + ueD + QL\overline{D} \\
& + Qu\overline{h} + Ln\overline{h} + h\overline{h}\phi
\end{aligned}$$

$U(1)_Y$ and $U(1)_{Z'}$

Field	$U(1)_{C''}$	$U(1)_{4'}$	$U(1)_{\zeta'}$	$U(1)_Y$	$U(1)_{Z'}$
Q_L^i	$+\frac{1}{2}$	0	$+\frac{1}{2}$	$\frac{1}{6}$	$-\frac{2}{3}$
u_L^i	$-\frac{1}{2}$	-1	$+\frac{1}{2}$	$-\frac{2}{3}$	$-\frac{2}{3}$
d_L^i	$-\frac{1}{2}$	$+1$	$+\frac{1}{2}$	$+\frac{1}{3}$	$-\frac{4}{3}$
e_L^i	$+\frac{3}{2}$	$+1$	$+\frac{1}{2}$	$+1$	$-\frac{2}{3}$
L_L^i	$-\frac{3}{2}$	0	$+\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{4}{3}$
n_L^i	$+\frac{3}{2}$	-1	$+\frac{1}{2}$	0	0
D^i	-1	0	-1	$-\frac{1}{3}$	$+\frac{4}{3}$
$\overline{D}^i$	$+1$	0	-1	$+\frac{1}{3}$	$+2$
H_2^i	0	$+1$	-1	$+\frac{1}{2}$	$+\frac{4}{3}$
H_1^i	0	-1	-1	$-\frac{1}{2}$	$+2$
N^i	0	0	$+2$	0	$-\frac{10}{3}$

The Superpotential

$$\begin{aligned} \mathcal{W} &= QuH_2 + QdH_1 + LeH_1 + LnH_2 \\ &\quad + \mathbf{H_1 H_2 N} + D\overline{D}N + \ldots \end{aligned}$$

We restrict our attention to the part of the scalar potential involving only the Higgs fields and the singlet under the assumption that squark and slepton fields have vanishing vacuum expectation values.
Consider

$$\mathcal{W} = H_1 H_2 N$$

where

$$H_1 = (H_1^0, H^-),$$
$$H_2 = (H^+, H_2^0)$$

are the Higgs fields and N denotes a singlet.

We compute the F-terms and D-terms. The F-terms are computed in the usual way.

The D-terms

For $SU(2)$ we have

$$D = -\frac{g}{2}\sigma^a_{ij}(H_1^{i\star}H_1^j + H_2^{i\star}H_2^j)$$

For $U(1)_Y$ we have

$$D' = -\frac{g'}{2}(|H_2|^2 - |H_1|^2)$$

For $U(1)_{Z'}$ we compute it to be

$$D'' = -2g''\left(|H_1|^2 + \frac{2}{3}|H_2|^2\right)$$

where $U(1)_{Z'}$ is defined to be orthogonal to $U(1)_Y$.

The Computation

$$
\begin{aligned}
V_F &= (|H_1|^2 + |H_2|^2)|N|^2 + |H_1 H_2|^2 \\
V_D &= \frac{g^2}{8}\left[2|H_1|^2|H_2|^2 - 4|H_1 H_2|^2 + |H_1|^4 + |H_2|^4\right] \\
&\quad + \frac{g'^2}{8}\left[|H_2|^2 - |H_1|^2\right]^2 \\
&\quad + 2g''^2\left[|H_1|^2 + \frac{2}{3}|H_2|^2\right]^2 \\
V_{soft} &= m_{H_1}^2|H_1|^2 + m_{H_2}^2|H_2|^2 + m_N^2|N|^2 - (A_1 H_1 H_2 N + h.c.)
\end{aligned}
$$

Minimization Conditions

We take a simple solution: $A_1 \in \mathbb{R}$. Making an $SU(2)_L \times U(1)_Y$ gauge transformation it is not restrictive to assume

$$v^+ \equiv \langle H^+ \rangle = 0, \qquad v_2 \equiv \langle H_2^0 \rangle \in \mathbb{R}^+.$$

Let $x = \rho_0 e^{i\phi_0}$ and $v_1 = \rho_1 e^{i\phi_1}$ for $\rho_0, \rho_1 \in \mathbb{R}^+$. The minimization condition on the phases of v_1 and x are computed as follows:

$$A_1 v_2 (v_1 x + v_1^* x^*) = 2A_1 v_2 \rho_0 \rho_1 \cos(\phi_1 + \phi_0) \Rightarrow \phi_1 + \phi_0 = 2\pi n, \quad n \in \mathbb{Z}.$$

$\langle V_{Higgs} \rangle = \langle V_{neutral} \rangle$

$$\begin{aligned}\langle V_{neutral} \rangle &= (x^2(v_1^2 + v_2^2) + v_1^2 v_2^2) \\ &\quad + \frac{g^2 + g'^2}{8}\left(v_1^2 - v_2^2\right)^2 + g''^2\left[v_1^2 + \frac{2}{3}v_2^2\right]^2 \\ &\quad + m_{H_1}^2 v_1^2 + m_{H_2}^2 v_2^2 + m_N^2 x^2 - 2A_1 v_1 v_2 x\end{aligned}$$

Soft SUSY Breaking Masses

$$
\begin{aligned}
m_{H_1}^2 &= A_1 \frac{v_2}{v_1} x + \frac{g^2 + g'^2}{4} (v_2^2 - v_1^2) \\
&\quad - 4 g''^2 \left[v_1^2 + \frac{2}{3} v_2^2 \right] - (x^2 + v_2^2) \\
m_{H_2}^2 &= A_1 \frac{v_1}{v_2} x + \frac{g^2 + g'^2}{4} (v_1^2 - v_2^2) \\
&\quad - \frac{8}{3} g''^2 \left[v_1^2 + \frac{2}{3} v_2^2 \right] - (x^2 + v_1^2) \\
m_N^2 &= A_1 \frac{v_1 v_2}{x} - (v_1^2 + v_2^2)
\end{aligned}
$$

Charged Higgs Boson Mass Matrix 1

$$\begin{pmatrix} x^2 + Av_1^2 + Dv_2^2 + m_{H_1}^2 & -v_1 v_2 + \frac{g^2}{2} v_1 v_2 + A_1 x \\ -v_1 v_2 + \frac{g^2}{2} v_1 v_2 + A_1 x & x^2 + Cv_2^2 + Dv_1^2 + m_{H_2}^2 \end{pmatrix}$$

$\Rightarrow$

$$-v_1 v_2 + \frac{g^2}{2} v_1 v_2 + A_1 x \begin{bmatrix} \frac{v_1}{v_2} & 1 \\ 1 & \frac{v_2}{v_1} \end{bmatrix}$$

where

$$\begin{aligned} A &= \frac{g^2 + g'^2 + 16g''^2}{4} \\ B &= \frac{32g''^2 - 3(g^2 + g'^2)}{12} \\ C &= \frac{9(g^2 + g'^2) + 64g''^2}{36} \\ D &= \frac{3(g^2 - g'^2) + 32g''^2}{12}. \end{aligned}$$

Then the physical charged Higgs field is given by

$$\begin{aligned} m_C^2 &= \left(\frac{v_1}{v_2}+\frac{v_2}{v_1}\right)\left[-v_1v_2+\frac{g^2}{2}v_1v_2+A_1x\right] \\ &= \left[-(v_1^2+v_2^2)+\frac{g^2}{2}\left[v_1^2+v_2^2\right]+2A_1\frac{x}{\sin 2\beta}\right)\right] \end{aligned}$$

and we find that

$$C^+ \equiv \cos\beta H^+ + \sin\beta H^-$$

and the orthogonal combination corresponding to the unphysical Goldstone boson

$$G^+ \equiv -\sin\beta H^+ + \cos\beta H^-.$$

Neutral Scalar Higgs Boson Mass Matrix

$$\begin{pmatrix} 2Av_1^2 + A_1\frac{v_2}{v_1}x & 2Bv_1v_2 - A_1x & 2xv_1 - A_1v_2 \\ 2Bv_1v_2 - A_1x & 2Cv_2^2 + A_1\frac{v_1}{v_2}x & 2xv_2 - A_1v_1 \\ 2xv_1 - A_1v_2 & 2xv_2 - A_1v_1 & A_1\frac{v_1v_2}{x} \end{pmatrix}$$

However, there are a few problems.

- It is very complicated to present analytic results for the diagonalization of this matrix.
- One is not sure that this matrix is semi-positive definite.

Neutral Pseudo-scalar Higgs Boson Mass Matrix

$$\begin{pmatrix} H^0_{1I} \\ H^0_{2I} \\ N_I \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta\cos\gamma & -\sin\beta\sin\gamma \\ -\sin\beta & \cos\beta\cos\gamma & -\cos\beta\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{pmatrix} \begin{pmatrix} G^0 \\ P_1 \\ P_2 \end{pmatrix}$$

The Superpotential One More Time

$$\begin{aligned} \mathcal{W} &= \mathbf{QuH_2} + QdH_1 + LeH_1 + LnH_2 \\ &+ \mathbf{H_1H_2N} + D\overline{D}N + \ldots \end{aligned}$$

One-Loop RGEs
Soft Breaking Potential

$$\mathcal{W} = QuH_2 + H_1H_2N$$

$$\begin{aligned} V_{soft} &= m_{H_1}^2|H_1|^2 + m_{H_2}^2|H_2|^2 + m_N^2|N|^2 + m_{\tilde{Q}}^2\tilde{Q}|\tilde{Q}|^2 + m_{\tilde{u}}^2|\tilde{u}|^2 \\ &\quad - (A_1H_1H_2N + h.c.) \\ &\quad - (A_1\tilde{Q}\tilde{u}H_2 + h.c.) \end{aligned}$$

What Needs Doing?

This is the next part which is currently being looked at. It involves the computation of the Yukawa couplings, trilinear scalar couplings and scalar masses.

What The Future Holds???

Johar M. Ashfaque

University of Liverpool

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THANKYOU!!!