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On Four Dimensional Nonsupersymetric String Models

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Outline

- Motivation.
- A Brief review of free fermionic models.
- Partition Functions of NAHE based models, orbifold constructions.
- SUSY breaking, interpolation between models.
- Some implications, gauge thresholds.
- Conclusions.

Free Fermionic Models

- In four dimensions one has the following fermionic field content: Left movers

$$\psi^{1,2}, \chi^{1,..,6}, y^{1,\dots,6}, \omega^{1,\dots,6}$$

  Right movers

$$\overline{y}^{1,\dots,6}, \overline{\omega}^{1,\dots,6}, \overline{\psi}^{1,..,5}, \overline{\eta}^{1,2,3}, \overline{\phi}^{1,\dots,8}$$

  total 64 real fermions
- Under a parallel transport around a non contractible loop fermions transform

$$f \rightarrow -e^{i\pi\alpha(f)} f$$

  A four dimensional vacuum is defined by a set of 64 dimensional vectors B_i with entries 0 and 1
- NAHE set (A.Faraggi, D. Nanopoulos 93) defined by $\{1, S, b_1, b_2, b_3\}$ (fields with $\alpha = 1$ are indicated explicitly)

$$S = \{\psi^{1,2}, \chi^{1,\dots,6}\}, \quad b_1 = \{\psi^{1,2}, \chi^{1,2}, y^{3,..,6} | \overline{y}^{3,..6} \overline{\psi}^{1,..,5}, \overline{\eta}^{1}\}$$

$$b_2 = \{\psi^{1,2}, \chi^{3,4}, y^{1,2} \omega^{5,6} | \overline{y}^{1,2} \overline{\omega}^{5,6} \overline{\psi}^{1,..,5}, \overline{\eta}^{2}\}$$

$$b_3 = \{\psi^{1,2}, \chi^{3,4}, \omega^{1,..,4} | \overline{\omega}^{1,..,4} \overline{\psi}^{1,..,5}, \overline{\eta}^{3}\}$$

Free Fermionic Models

- NAHE set gives a gauge group $SO(10) \times SO(6)^3 E_8$ with $N = 1$ SUSY
- Extra vectors (α, β, γ) reduce the number of generations down to three (G.Cleaver,A.Faraggi, C.Savage 01). The gauge group is either $SU(5) \times U(1)$, or $SO(6) \times SO(4)$,or $SU(3) \times SU(2) \times U(1)^3$ or $SU(3) \times SU(2)^2 \times U(1)$
- Orbifold constructions: The set $\{1, S, b_1, b_2, \xi_1, \xi_2\}$ with

$$\xi_1 = \{\overline{\psi}^{1,..,5}, \overline{\eta}^{1,2,3}\}, \quad \xi_2 = 1 + b_1 + b_2 + b_3$$

  corresponds to the $Z_2 \times Z_2$ orbifold with standard embedding. The Euler characteristic of this models is 48 with $h_{11} = 27$ and $h_{21} = 3$.
- Introducing extra vector

$$\gamma = \{\overline{\psi}^{1,\dots,5}, \overline{\eta}^{1,2,3}, \overline{\phi}^{1\dots,4}\}$$

  breaks $E_8 \times E_8$ gauge symmetry down to $SO(16) \times SO(16)$, whereas $Z_2 \times Z_2$ orbifold further breaks it down to $SO(4)^3 \times SO(10) \times U(1)^3 \times SO(16)$.
- At the level of $N = 4$ SUSY the set $\{1, S, \xi_1, \xi_2\}$ defines two models (denoted as Z_+ and Z_-) depending on the sign of the generalized GSO projection. Z_+ model has the gauge symmetry $E_8 \times E_8$ and Z_- model has the gauge symmetry $SO(16) \times SO(16)$.

Partition Functions of NAHE based models

- We would like to understand these results in the framework of the bosonic formulation of the heterotic superstring, in order to further explore better the corresponding vacua - not only at the special point of the moduli space.
- The partition functions for the Z_- and Z_+ vacua are given by

$$
\begin{aligned}
Z_- \quad = \quad & \frac{(V_8 - S_8)}{\tau_2(\eta\bar{\eta})^8} \times \Big[\; \left(|O_{12}|^2 \; + \; |V_{12}|^2 \;\right) \left(\overline{O}_{16}\overline{O}_{16} + \overline{C}_{16}\overline{C}_{16}\right) \\
& + \left(|S_{12}|^2 \;\; + |C_{12}|^2 \;\right) \left(\overline{S}_{16}\overline{S}_{16} + \overline{V}_{16}\overline{V}_{16}\right) \\
& + \left(O_{12}\overline{V}_{12} + V_{12}\overline{O}_{12}\right) \left(\overline{S}_{16}\overline{V}_{16} + \overline{V}_{16}\overline{S}_{16}\right) \\
& + \left(S_{12}\overline{C}_{12} + C_{12}\overline{S}_{12}\right) \left(\overline{O}_{16}\overline{C}_{16} + \overline{C}_{16}\overline{O}_{16}\right)\Big]
\end{aligned}
$$

$$
Z_+ = \frac{(V_8 - S_8)}{\tau_2(\eta\bar{\eta})^8} \left[|O_{12}|^2 + |V_{12}|^2 + |S_{12}|^2 + |C_{12}|^2\right] \left(\overline{O}_{16} + \overline{S}_{16}\right) \left(\overline{O}_{16} + \overline{S}_{16}\right)
$$

- These two models can be connected by an orbifold

$$
Z_- = Z_+/a \otimes b, \quad a = (-1)^{F_{\rm L}^{\rm int} + F_{\xi}^{1}}, \quad b = (-1)^{F_{\rm L}^{\rm int} + F_{\xi}^{2}}
$$

- This can be generalised to an arbitrary point in moduli space and hence used to to construct orbifold models that originate from Z_- partition functions.

Partition Functions of NAHE based models

- Similar connection between Z_- and Z_+ models can be established for the case of one compactified dimension.
- Considering the compactification on the circle with the shift one find the orbifold

$$Z_2 \ : \ g = (-1)^{F_{\xi^1}} \delta, \quad Z_2' \ : \ g' = (-1)^{F_{\xi^2}} \delta$$

$$\delta X^9 = X^9 + \pi R \ , \xi_1 = \{\bar{\psi}^{1,\cdots,5}, \bar{\eta}^{1,2,3}\}, \quad \xi_2 = \{\bar{\phi}^{1,\cdots,8}\}$$

- In ten dimensions the model is generated by the basis vectors $\{1, \xi_1, \xi_2\}$ and $S = 1 + \xi_1 + \xi_2$. The choice of the generalised GSO coefficient

$$\binom{\xi_2}{\xi_1} = -1$$

  reduces the gauge symmetry form $E_8 \times E_8$ to $SO(16) \times SO(16)$
- The corresponding projection in the bosonic formulation is

$$\frac{1 + (-1)^{F + F_{\xi_1}}}{2} \times \frac{1 + (-1)^{F + F_{\xi_2}}}{2}$$

- In the free fermionic case the same phase that reduces the gauge symmetry in the compactified model projects out the supersymmetry generator in the uncompactified theory.

Interpolation between models

- Compactify the heterotic $E_8 \times E_8$ model on a circle S^1_1 moded by $Z_2 \times Z'_2$ orbifold

$$Z_2 \; : \; g = (-1)^{F_{\xi^1}} \delta_1 , \quad Z'_2 \; : \; g' = (-1)^{F_{\xi^2}} \delta_1$$

$$\delta_1 \; : \; X_9 \; \rightarrow \; X_9 + \pi R_9 \quad \Rightarrow \quad \Delta_{mn} \; \rightarrow \; (-1)^m \Delta_{mn}$$

- The resulting theory is a heterotic string with $SO(16) \times SO(16)$ gauge symmetry and $N = 1$ SUSY.
- Compactify this model on S^1_2 moded by Z''_2 where

$$Z''_2 \; : \; g'' = (-1)^{F + F_{\xi^1} + F_{\xi^2}} \delta_2$$

$$\delta_2 \; : \; X_8 \; \rightarrow \; X_8 + \pi R_8 \quad \Rightarrow \quad \Gamma_{mn} \; \rightarrow \; (-1)^m \Gamma_{mn} \; .$$

- Then in the limit $R_8 \rightarrow 0$ we get a ten dimensional nonsupersymmetric $SO(16) \times SO(16)$ heterotic string compactified on a circle S^1 moded by the $Z_2 \times Z'_2$ orbifold.
- The decompactification limit $R_8 \rightarrow \infty$ the nonsypersymmetric heterotic string interpolates to the $SO(16) \times SO(16)$ heterotic string in nine dimensions moded by the $Z_2 \times Z'_2$ orbifold.
- One can do the same interpolation when comactifying down to four dimensions, gauge thresholds interpolate in a similar way.

Conclusions and the Discussion

- Nonsupersymmetric vacua, and their role in the string duality picture requires more study.
- Their low energy field theoretic description.
- Geometrical structure underlying theses models.
- How stable they are.
- Relevant phenomenology.
- Many other questions.