QUARK, LEPTON AND NEUTRINO MASSES IN HORAVA-WITTEN INSPIRED MODELS

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Horava-Witten M-Theory offers new ways in achieving the quark and lepton mass
hierarchies not naturally available in supergravity unified models. In previous
work, based on a torus fibered Calabi-Yau manifold with a del Pezzo base dP7,a
three generation SU(5) model with Wilson line breaking to the Standard Model
was constructed. It was seen that if the additional 5-branes clustered near the
distant orbifold plane, it was possible that such models could generate the observed
hierarchies of quark masses without undue fine tuning. We update these results
here and extend them to include the charged leptons. A new mechanism for gen-
erating small neutrino masses (different from the usual seesaw mechanism)arises
naturally from a possible cubic holomorphic term in the Kahler potential when
supersymmetry is broken. We show that the LMA solution to neutrino masses
can occur, with a good fit to all neutrino oscillation data. The model implies the
existence of the $\mu \rightarrow e\gamma$ decay even for universal slepton soft breaking masses, at
rates accessible to the next round of experiments.

1. Introduction

Over the past year considerable progress has been made in understanding
Horava-Witten heterotic M-theory 1 with “non-standard” embeddings2. In
this picture, space has an 11 dimensional orbifold structure of the form (to
lowest order) $M_4 \times X \times S^1/Z_2$ where $M_4$ is Minkowski space, $X$ is a 6D
Calabi-Yau space, and $-\pi \rho \leq x^{11} \leq \pi \rho$. The space thus has two orbifold
10D manifolds $M_4 \times X$ at the $Z_2$ fixed points at $x^{11} = 0$ and $x^{11} = \pi \rho$
where the first is the visible sector and the second is the hidden sector,
each with an apriori $E_8$ gauge symmetry. In addition there can be a set of
5-branes in the bulk at points $0 < x_n < \pi \rho$, $n = 1...N$ each spanning $M_4$
to preserve Lorentz invariance) and wrapped on holomorphic curve in $X$
to preserve N=1 supersymmetry).

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In general, physical matter lives on the $x^{11} = 0$ orbifold plane and only gravity lives in the bulk. The existence of 5-branes allows one to satisfy the cohomological constraints with $E_8$ on $x^{11} = 0$ breaking to $G \times H$ where $G$ is the structure group of the Calabi-Yau manifold and $H$ is the physical grand unification group. We consider the case $G = SU(5)$, and $H = SU(5)$.

In this picture, three generation models with Wilson line breaking $SU(5)$ to $SU(3) \times SU(2) \times U(1)$ have been constructed using torus fibered Calabi-Yau manifolds (with two sections)\(^3\). Also, the general structure (to the first order) of the Kahler metric of the matter field has been constructed\(^4\). In general such models do not naturally give rise to observed quark/lepton mass hierarchies. It was shown\(^5\), however, that models with vanishing first Pontrjagin class on the physical orbifold, $\beta_i^{(0)}$ can lead to Yukawa textures with all CKM and quark mass data without any undue fine tuning, and three generation model with Wilson line breaking of $SU(5)$ to SM exists provided the Calabi-Yau manifold has del Pezzo base $dP_7$. (The possibility that vanishes is non-trivial since it is forbidden in elliptically fibered Calabi-Yau manifold\(^6\).) Within this framework, in this note, we evaluate the charged lepton masses, neutrino masses and the mixing angles and explore the signal of this model in the rare decay modes of leptons.

2. Kahler Metric

The bose part of the 11 dimensional gravity multiplet consists of the metric tensor $g_{IJK}$, the antisymmetric 3-form $C_{IJK}$ and its field strength $G_{IJKL}$ ($I, J, K = 1 \ldots 11$). The $G_{IJKL}$ obey field equations $D_I G_{IJKL} = 0$ and Bianchi identities

$$(dG)_{11RSTU} = 4\sqrt{2} \pi \left( \frac{\kappa}{4\pi} \right)^{2/\beta} [J^0 \delta(x^{11}) + J^{N+1} \delta(x^{11} - \pi \rho)]
+ \frac{1}{2} \sum_{n=1}^{N} J^n (\delta(x^{11} - x_n) + \delta(x^{11} + x_n))]_{RSTU}$$

Here $(\kappa^{2/3})$ is the 11D Planck scale($k_{11}$), and $J^n$, $n = 0, 1, \ldots N + 1$ are sources from orbifold planes and the $N$ 5-branes. These equations can be solved perturbatively in powers of $(\kappa^{2/3})^4$. The effective 4D theory can then be characterized by a Kahler potential $K = Z_{IJ} C^I C^J$, Yukawa couplings $Y_{IJK}$ for the matter fields $C^I$ and gauge functions from the physical orbifold plane $x^{11} = 0$. To first order, $Z_{IJ}$ takes the form \(^4\).

$$Z_{IJ} = e^{-K^{I}/3} [G_{IJK} - \frac{e}{2\pi} \tilde{F}_I^J \sum_{n=0}^{N+1} (1 - z_n)^{2 \beta_i^{(n)}}]$$

(2)
3. Phenomenological Yukawa Matrices

One expects $G_{IJ}$, $\tilde{\Gamma}_{IJ}$ and $Y_{IJK}$ to be characteristically of $O(1)$, and the parameter $\epsilon$ is not too small. However, the second term will be small if $\beta_i^{(0)}$ were to vanish and if the 5-branes were to be near the distant orbifold plane i.e. $d_n = 1 - z_n$ were small. In the following we will assume then that $\beta_i^{(0)} = 0$; $d_n = 1 - z_n \approx 0.1$.

A phenomenological example for the quark contributions with these properties (and containing the maximum numbers of zeros) is ($f_T \equiv \exp(-k_T/3)$):

$$Z^u = f_T \begin{pmatrix} 1 & 0.345 & 0 \\ 0.345 & 0.131 & 0.636d^2 \\ 0 & 0.636d^2 & 0.34d^2 \end{pmatrix}; Z^d = f_T \begin{pmatrix} 1 & 0.49 & 0 \\ 0.49 & 0.56 & 0.43 \\ 0 & 0.43 & 0.72 \end{pmatrix}.$$ (3)

with Yukawa matrices $\text{diag}Y^u = (0.01, 0.06, 0.1 \exp(0.65i))$ and $\text{diag}Y^d = (2, 0.25, 1.82)$.

Thus to obtain the physical Yukawa matrices, one must first diagonalize the Kahler metric and then rescale it to unity. Then using the renormalization group equations, one can generate the CKM matrix, and the quark masses. We use tan $\beta = 40$ in our analysis. We obtain the correct quark masses and mixing angles. We also get the CP violating parameter $\sin 2\beta = 0.8$ which agrees well with the experimental data.

In order to obtain correct charged lepton masses, we need:

$$Z^l = f_T \begin{pmatrix} 1 & -0.547 & 0 \\ -0.547 & 0.43 & 0.025 \\ 0 & 0.025 & 0.09 \end{pmatrix}; Z^{e_R} = f_T \begin{pmatrix} 1 & 0.624 & 0 \\ 0.624 & 0.4 & 0.57d^2 \\ 0 & 0.57d^2 & 0.44d^2 \end{pmatrix}.$$ (4)

And Yukawa matrix $\text{diag}Y^l = (0.3, 3, 1.82)$.

4. neutrino masses and mixing angles

The small neutrino masses and the near bi-maximal mixing (as required by the recent experimental data) arise from a Kahler potential term in this model: $k_{11}/f_T^{3/2} \sqrt{G_{H_2}} \lambda_\nu L \nu_R H_u$. Under a Kahler transformation, we get the following term in the superpotential:

$$\frac{k^2_{3}}{f_T^{3/2} \sqrt{G_{H_2}}} < W_h > \frac{k_{11}}{3} \lambda_\nu L \nu_R H_u,$$ (5)

where $k^2_{3} = 8\pi G_N$. $W_h$ is the hidden sector superpotential. Now using

$$Z^\nu = f_T \begin{pmatrix} 1 & -0.465 & 0 \\ -0.465 & 0.31 & 0.025 \\ 0 & 0.025 & 0.028 \end{pmatrix}.$$ (6)
with \( \text{diag} Y^i = (4, 0.1, 4) \), we generate the following neutrino masses: \((2.4 \times 10^{-3}, 1.4 \times 10^{-2}, 1)x\), where \( x = k_4^2 < W_h > k_{11}/f_T^{3/2} \sqrt{G_{H_2}} \) and mixing angles: \( \tan^2 \theta_{12} = 0.41, \tan^2 \theta_{23} = 0.89 \).

5. Lepton flavor violation

Since the physical lepton couplings are flavor non diagonal, we get appreciable lepton flavor violating decay of \( \mu \rightarrow e\gamma \). We use the minimal SUGRA framework i.e. universal scalar, gaugino masses and trilinear A terms at the GUT scale to calculate the branching ratio (BR) of this decay. We plot the BR as a function of \( m_{1/2} \) in Fig.1 for \( A_0 = 2m_{1/2} \) and \( A_0 = -2m_{1/2} \). We find that the BR can be observed in the upcoming PSI experiment.

In our calculation, we satisfy the dark matter relic density constraint i.e. \( 0.07 < \Omega \chi_1 h^2 < 0.25 \). The BR of \( \tau \rightarrow \mu \gamma \) is small. This work was supported in part by the National Science Foundation Grant PHY - 0101015.

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