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MSSM-like from $SU_5 \times D_4$ models

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Abstract

Using finite discrete group characters and symmetry breaking by hyperflux as well as constraints on top-quark family, we study minimal low energy effective theory following from $SU_5 \times D_4$ models embedded in F-theory with non-abelian flux. Matter curves spectrum of the models is obtained from $SU_5 \times S_5$ theory with monodromy S_5 by performing two breakings: first from symmetric group S_5 to S_4 subsymmetry, and next to dihedral D_4 subgroup. As a consequence, and depending on the ways of decomposing triplets of S_4, we end with three types of D_4-models. Explicit constructions of these theories are given and a MSSM-like spectrum is derived.
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1. Introduction

Recently, there has been an increasing interest in building $SU_5 \times \Gamma$ GUT models, with discrete symmetries Γ, embedded in Calabi–Yau compactification of F-theory down to 4D space time [1–11]; and in looking for low energy minimal prototypes with broken monodromies [12–19]. This class of supersymmetric GUTs with discrete groups leads to quasi-realistic field spectrum having quark and lepton mass matrices with properties fitting with MSSM requirements. In the geometric engineering of these F-GUTs, splitting spectral cover method together with Galois

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theory tools is used to generate appropriate matter curves spectrum [20–25]; and a *geometric* Z_2 parity has been also introduced to suppress unwanted effects such as exotic couplings and undesired proton decay operators [26–29].

In this paper, we develop another manner to deal with monodromy of F-GUT that is different from the one proposed first in [18], and further explored in [27,30,31], where matter curves of the same orbit of monodromy are identified. In our approach, we use the non-abelian flux conjecture of [15,16] to think of monodromy group of F-theory SU_5 models as a non-abelian flavor symmetry Γ. Non-trivial irreducible representations of the non-abelian discrete group Γ are used to host the three generations of fundamental matter; a feature that opens a window to build semi-realistic models with matter curves distinguished from each other in accord with mass hierarchy and mixing neutrino physics [32–34].

In this work, we study the family of supersymmetric $SU_5 \times \Gamma_p \times U(1)^{5-p}$ models in the framework of F-theory GUT; with *non-abelian* monodromies Γ_p contained in the permutation group $\mathbb{S}_5$ [30–42]; and analyse the realisation of low energy constraints under which one can generate an effective field spectrum that resembles to MSSM. A list of main constraints leading to a good low energy spectrum is described in section 5; it requires amongst others a tree-level Yukawa coupling for top-quark family. To realise this condition with non-abelian Γ_p, we consider the case where Γ_p is given by the order *8* dihedral group $\mathbb{D}_4$; this particular non-abelian discrete symmetry has representations which allow more flexibility in accommodating matter generations. Recall that the non-abelian alternating $\mathbb{A}_4$ group has no irreducible doublet as shown in the character relation $12 = 3^2 + 1^2 + 1^2 + 1^2$; and the irreducible representation of non-abelian $\mathbb{S}_4$ and $\mathbb{S}_3$, which can be respectively read from $24 = 3^2 + 3^2 + 2^2 + 1^2 + 1^2$ and $6 = 2^2 + 1^2 + 1^2$, has a doublet and two singlets. The non-abelian dihedral group $\mathbb{D}_4$ however has representations $\boldsymbol{R}_i$ with dimensions, that can be read from $8 = 2^2 + 1^2 + 1^2 + 1^2 + 1^2$, seemingly more attractable phenomenologically; it has *5* irreducible $\boldsymbol{R}_i$'s, four singlets, indexed by their basis characters as $\mathbf{1}_{++}$, $\mathbf{1}_{+-}$, $\mathbf{1}_{-+}$, $\mathbf{1}_{--}$, and an irreducible doublet $\mathbf{2}_{00}$, offering therefore several pictures to accommodate the three generations of matter of the electroweak theory; in particular more freedom in accommodating top quark family.

To deal with the engineering of $SU_5 \times \mathbb{D}_4$-models, we develop a *new method* based on finite discrete group characters $\chi_{\boldsymbol{R}_i}$, avoiding as a consequence the complexity of Galois theory approach. The latter is useful to study F-theory models with the dihedral $\mathbb{D}_4$ and the alternating $\mathbb{A}_4$ subgroups of $\mathbb{S}_4$ as they are not directly reached by the standard splitting spectral cover method; they are obtained in Galois theory by putting constraints on the discriminant of underlying spectral covers, and introducing other monodromy invariant of the covers such a resolvent [14,15,29].

To derive the $\mathbb{D}_4$-matter curves spectrum in $SU_5 \times \mathbb{D}_4$-models, we think of it in terms of a two steps descent from $\mathbb{S}_5$-theory: a first descent down to $\mathbb{S}_4$, and a second one to $\mathbb{D}_4$ by turning on appropriate flux that will be explicitly described in this work, see also appendix C. By studying all scenarios of breaking the triplets $\mathbb{S}_4$-theory in terms of irreducible $\mathbb{D}_4$-representations, we end with three kinds of $\mathbb{D}_4$-models: one having a field spectrum involving all $\mathbb{D}_4$-representations including doublet $\mathbf{2}_{00}$ (*model I*), the second theory (*model II*) has no doublet $\mathbf{2}_{00}$ nor the singlet $\mathbf{1}_{--}$, and the third model has no $\mathbf{2}_{00}$, but does have $\mathbf{1}_{--}$. We have studied the curves spectrum of the three $\mathbb{D}_4$-models; and we have found that only model III allows a tree level 3-couplings and exhibits phenomenologically interesting features.

The presentation is as follows: In section 2, we study the $SU_5 \times \mathbb{S}_5$ model, and describe the picture of the two steps breaking $\mathbb{S}_5 \to \mathbb{S}_4 \to \mathbb{S}_3$ by using standard methods. In section 3, we introduce our method; and we revisit the construction of the $\mathbb{S}_4$- and $\mathbb{S}_3$-models from the view of discrete group characters. In section 4, we use character group method to build three

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