Theory and Phenomenology of Neutrino Masses and Mixing in the Light of Latest Neutrino and Cosmology Data

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Chapter 5

Conclusion and Future Prospects

It is clear that inspite of the many successes achieved in particle physics through the formulation of Standard Model, there are many drawbacks associated with this model. The quest to find answers to these limitations made people to explore different possible alternatives that gave birth to frameworks which are popularly termed as Beyond Standard Model physics. These BSM frameworks aim to study and explain the processes of neutrino mass generation, dark matter, baryon asymmetry of the universe and reactions that involve lepton number and lepton flavor violations. These phenomena are prevalent across the fields of cosmology, astrophysics and particle physics.

In this thesis we have tried to address these challenging issues by constructing some models using modular and discrete flavor symmetry in the framework of minimal inverse seesaw. We have studied these phenomena in these models and tried to reproduce relic density for dark matter, effective Majorana mass for electron neutrino, BAU in our work. Accordingly we have divided this thesis into five different chapters. The first chapter includes an introduction of the thesis. Here we have discussed about the developments related to neutrino physics in last couple of decades. This is followed by a discussion on Standard Model of particle physics, along with a brief description about the prominent drawbacks of this scheme. Here we have also discussed about the different groups, such as A_4 and modular groups $\Gamma(3)$, that we have used in constructing the models for our work. Taking them as the basis, we have performed rest of the studies and analysis of this thesis.

The second chapter of this thesis contains the work we have done in one of the models that we have constructed using $\Gamma(3)$ modular group in ISS(2,3). As mentioned earlier, this modular group which is isomorphic to non-abelian discrete group A_4 has three Yukawa modular forms of weight 2. We have extended the particles of ISS(2,3) with a flavon ϕ, which helps to get a diagonal charged lepton mass matrix. Along with neutrino phenomenology, we have studied neutrinoless double beta decay and lepton flavor violating processes in this model. In this case we have considered the cLFV process $\mu \to e\gamma$, for which we have calculated its branching ratio. We have also calculated the effective Majorana mass for electron neutrinos, which is one of the important parameters related to NDBD. From our analysis we find that the model successfully produces the different parameters associated with neutrinos in the allowed 3σ ranges. Also the model is compatible with the experimental data related to NDBD and cLFV.

In Chapter 3 we present our analysis on baryon asymmetry of the universe and dark matter which are two important issues is cosmology as well as in particle physics. For this study, we have constructed another model by extending ISS(2,3) with a flavon ϕ and a Higgs-like scalar triplet $\eta = (\eta_1, \eta_2, \eta_3)$. In our model we have used A_4 modular symmetry to describe various interactions among the fields present in this setup. After electroweak symmetry breaking, only one of the η's acquire VEV and the other two components do not acquire any such value. These two neutral components of η are the probable dark matter candidates in our work. Accordingly we have calculated the relic density and found that the model is able to produce its latest value as observed by Planck collaboration. Furthermore, we have studied baryon asymmetry by using the popular mechanism of resonant leptogenesis. The heavy fermions present in minimal inverse seesaw forms two pairs of quasi-Dirac particles. We have determined the asymmetry created by decay of the lightest quasi-Dirac pair, which is eventually converted into baryon asymmetry that is observed in the universe. It is found that the results obtained from the model are consistent with the predictions obtained from various cosmological observations and related experiments. We have also evaluated the neutrino parameters and found them to lie within the allowed range as predicted by the latest 3σ nu-fit values.

In the fourth chapter we try to study the origin of texture zero conditions of light neutrino mass matrix. Here we have discussed a model that has been built using discrete flavor symmetry in minimal inverse seesaw mechanism. Along with two right-handed neutrinos and three sterile fermions, this model contains five flavons $(\phi, \chi, \chi', \zeta, \zeta')$ and a Higgs-like scalar triplet field η. In order to construct the lagrangian of the model we have used non-abelian discrete symmetry group A_4. The three matrices of ISS(2,3) i.e. M_D, M_{NS} and M_S play a very crucial role in determining the structure of light neutrino mass matrix. In our work, we have fixed the structures of M_{NS} and M_S with specific VEV alignments of ζ and ζ'. We then try to obtain texture zero structures by implementing 2-0 conditions to M_D. Interestingly we find that out of the fifteen possible 2-0 conditions of M_D, only six of them are able to produce 1-0 structures of neutrino mass matrix. Moreover, only two of these six cases (M_{D3} and M_{D6}) were able to generate all the neutrino mixing angles for normal hierarchy. So we considered only these two cases for further studies. Accordingly we found out the values of model parameters and analysed dark matter for these two cases of M_D. The outcomes of our analysis are consistent with experimental and cosmological observations, thereby, validating the compatibility of this model.

In the future we plan to extend our work to understand the non-standard interactions of neutrinos. This study will provide more insights about δ_{CP} phase, impacts on CP violation etc. Also we will try to study the effects of stochastic gravitational waves in the models that we have constructed in this thesis and try to find if they can be used to analyse the same.