Abstract

After the remarkable discovery of the Higgs boson at the Large Hadron Collider (LHC) in 2012, the standard model (SM) of particle physics has been established as the most successful theory of elementary particles and their fundamental interactions except gravity. However, there are convincing reasons to believe that there is new physics beyond the standard model (BSM) as several observed phenomena as well as theoretical questions remain unanswered in the SM. Among such observed phenomena, the presence of dark matter (DM) giving rise to around 26% of the present Universe is very appealing. Although the first evidence for DM appeared in the 1930s, it was only in the early 1980s that astronomers were convinced of the fact that most of the mass holding galaxies and clusters of galaxies together is non-luminous. Since the nature of particle DM and its interactions with the SM particles, except gravitational interactions, are not yet known, there exist two broad scenarios: one in which DM couples to SM with couplings of the order of electroweak interactions and one in which DM-SM couplings are very feeble. The first scenario, popularly known as the weakly interacting massive particle (WIMP) paradigm, is the most studied particle DM candidate in the literature. WIMP can be defined as a new elementary particle whose interaction strength is as weak as or weaker than the weak nuclear force. The typical mass range for WIMPs can vary from a few GeV to a few TeV. WIMPs can be thermally produced in the early Universe through their interaction with the bath particles. Their relic abundance can be found from the very well known "freeze-out" mechanism. WIMPs can also leave observable signatures at several direct, indirect search experiments by virtue of their sizeable interactions. While no such observations have been made yet, the other scenario, known as the feebly interacting massive particle (FIMP) scenario, has also gained attention in the last few years. In this paradigm, DM will have very feeble interaction with SM particles, which prevents them from getting produced thermally in the early Universe. However, it is extremely difficult to produce or detect such particles directly in our ongoing experiments.

Another observed phenomena is the existence of tiny but non-zero neutrino mass and large mixing, which have been confirmed by several neutrino experiments for more than two decades till now. Specially, the more recent experimental results have not only confirmed the results from earlier experiments but also discovered the non-zero reactor mixing angle θ_{13}. The two most important unknowns at present in the neutrino sector are the mass hierarchy: whether it is normal ($m_3 > m_2 > m_1$) or inverted ($m_2 > m_1 > m_3$), and the leptonic Dirac CP phase δ. Apart from neutrino oscillation experiments, the neutrino sector is constrained by the data from cosmology and rare decay experiments. For example, the combined data from the Planck 2018 and BAO experiments constrains the sum of absolute neutrino masses $\sum_i |m_i| < 0.12$ eV at 95% CL. If there are no right-handed neutrinos, the Higgs field, which

lies at the origin of all massive particles in the SM, can not have any Dirac Yukawa coupling with the neutrinos. If we include right-handed neutrinos by hand without a Majorana mass for the right-handed neutrinos, the required Yukawa couplings are extremely small, around 10^{-12} or smaller, usually considered as unnatural. Additionally, a bare mass term of the right-handed neutrinos is allowed by gauge symmetries, introducing a new scale outside the purview of the SM.

The purpose of this thesis is to study minimal models of scalar or fermion DM, where light neutrino mass can also arise naturally with a non-trivial connection to the DM sector. To do that, we have extended the particle content as well as the symmetry of the SM either by gauge or global symmetries and studied their phenomenological consequences. We have shown that such symmetries not only stabilize DM but also play a crucial role in generating neutrino mass and mixing. We elaborate upon direct and collider search prospects of the models both in the context of WIMP, and in some specific scenarios, we have also discussed the possibilities of constraining the model from the cosmological observations like effective relativistic degrees of freedom (DOF) in cosmic microwave background (CMB). We have also discussed the interplay of thermal and non-thermal contribution to DM relic density. The thesis has been divided into five chapters. We have started with a brief introduction of the DM physics and the neutrino mass generation mechanism in chapter 1. In chapter 2, we have studied a class of a very well motivated BSM framework based on the gauged $\mathrm{B-L}$ extension of the SM with B, L being baryon and lepton numbers, respectively. This minimal and economical model generating nonzero neutrino mass has been studied for a long time. The most interesting feature of the minimal version of this framework is that the inclusion of three right-handed neutrinos, as it is done in the type I seesaw mechanism of generating light neutrino masses, is no longer a choice but a necessity due to the requirement of the new $\mathrm{U(1)_{B-L}}$ gauge symmetry to be anomaly free. We have discussed three different versions of the model where neutrino mass (either Majorana or Dirac) and DM physics, namely the stability, type and number of DM candidates are dictated by the anomaly cancellation requirements. In chapter 3, we consider the possibility of probing the left-right symmetric model (LRSM) via the CMB. LRSM has been one of the most popular BSM frameworks studied in the literature. Here the gauge symmetry of the SM is extended to $\mathrm{SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}$ so that the right-handed fermions (which are singlets in SM) can form doublets under the new $SU(2)_R$. This not only makes the inclusion of right-handed neutrino automatic, but also puts the left and right-handed fermions on equal footing. Due to the presence of gauge interactions of the right-handed neutrinos, they can be thermally produced in the early Universe and contribute to the total effective relativistic DOF and can be significantly constrained. The chapter 4 discusses the role of discrete symmetries in physics of DM and neutrinos. It is based on two different scenarios where the relic abundance of DM is generated either from a hybrid of thermal and non-thermal mechanisms or from purely non-thermal mechanism. While in the first scenario, $\mathbb{Z}_2$ symmetry plays the role of stabilizing DM and generating radiative neutrino mass, in the latter scenario, the non-abelian discrete symmetry group A_4 is implemented to generate light neutrino mass and mixing. In the first case, we have shown that a thermally under-abundant DM candidate can get non-thermal contribution to satisfy relic density bounds. The second section is dedicated to providing a common framework explaining the origin of tiny couplings required for light Dirac neutrinos and non-thermal DM. In chapter 5, we have summarized our discussion and mentioned the future directions.