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Dark matter assisted Dirac leptogenesis and neutrino mass

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Abstract

We propose an extension of the standard model with $U(1)_{B-L} \times Z_2$ symmetry. In this model by assuming that the neutrinos are Dirac (*i.e.* $B-L$ is an exact symmetry), we found a simultaneous solution for non zero neutrino masses and dark matter content of the universe. The observed baryon asymmetry of the universe is also explained using Dirac Leptogenesis, which is assisted by a dark sector, gauged under a $U(1)_D$ symmetry. The latter symmetry of the dark sector is broken at a TeV scale and thereby giving mass to a neutral gauge boson Z_D. The standard model Z-boson mixes with the gauge boson Z_D at one loop level and paves a way to detect the dark matter through spin independent elastic scattering at terrestrial laboratories.

1. Introduction

The standard model (SM), which is based on the gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$, is a successful theory of fundamental particles of nature and their interactions. After the Higgs discovery, it seems to be complete. However, there are many unsolved issues which are not addressed within the framework of SM. In particular, the non-zero neutrino masses, baryon asym-

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metry of the Universe, existence of dark matter *etc*. These problems beg for a successful theory in physics beyond the SM.

The observed galactic rotation curve, gravitational lensing and large scale structure of the Universe collectively hint towards the existence of an invisible matter, called dark matter. In fact, the relic abundance of dark matter has been precisely determined by the satellite based experiments, such as WMAP [1] and PLANCK [2] to be $\Omega_{\rm DM}h^2 = 0.1199 \pm 0.0027$. Hitherto the existence of dark matter is shown in a larger scale ($\gtrsim$ a few kpc) only via its gravitational interaction. However, the particle nature of dark matter is remained elusive till today and needs to be explored in a framework of physics beyond the SM.

Within the SM, the neutrinos are exactly massless. This can be traced to a conserved B–L symmetry within the SM, where B and L stands for net baryon and lepton number respectively. However, the oscillation experiments [3–5] have successfully demonstrated that the neutrinos have sub-eV masses. One attractive way to explain the small masses of active neutrinos is to introduce the lepton number violation by two units through the dimension five operator $\ell\ell HH/\Lambda$ [6], where ℓ, H are the lepton and Higgs doublet respectively and Λ is the scale at which the new physics is expected to arise. After electroweak phase transition, the neutrinos acquire a Majorana mass of the order $m_\nu = \langle H\rangle^2/\Lambda$. Naively this implies that the sub-eV masses of neutrinos indicate the scale of new physics to be $\Lambda \sim \mathcal{O}(10^{14})$ GeV. Note that the effective dimension-5 operator can be realized in many extensions of the standard model, the so called seesaw mechanisms [7–9]. In these models, the mass scale of new particles is expected to be at a scale of Λ. Therefore, it is imagined that in the early Universe, when the temperature of thermal bath is high enough, namely $T \gtrsim \Lambda$, the lepton number violation can occur rapidly, while it is suppressed today. As a result, a net lepton asymmetry [10,11] can be generated through CP violating out-of-equilibrium decay [12] of these heavy particles at $T \sim \Lambda$, which is then converted to the observed baryon asymmetry of the Universe through the electroweak sphaleron transitions. The lepton number violating interactions ($\Delta L = 2$), which also indicate Majorana nature of neutrinos, can be proved at ongoing neutrinoless double beta decay experiments [13]. But till now there is no positive result found in those experiments. So there is still a chance of hope that the neutrinos might be Dirac in nature. In other words, B–L is an exact global symmetry of the SM Lagrangian.

Even the neutrinos are Dirac in nature (i.e. B–L is exactly conserved), the baryon asymmetry of the Universe must be explained since it is an observed fact. It has been explored largely in the name of Dirac leptogenesis [14–20], which connect Dirac mass of neutrinos with the observed baryon asymmetry of the Universe. The key point of this mechanism is that the equilibration time between left and right-handed neutrinos mediated via SM Higgs (i.e. $Y\overline{\nu_R}H\nu_L$) is much less than the $(B+L)$ violating sphaleron transitions above electroweak phase transition. Therefore, if we demand that $B - L = B - (L_{\rm SM} + L_{\nu_R}) = 0$ [15], then we see that a net $B - L_{\rm SM}$ is generated in terms of L_{ν_R}. The electroweak sphalerons will not act on L_{ν_R}, as ν_R is singlet under $SU(2)_L$, while the non-zero $B - L_{\rm SM}$ will be converted to a net B asymmetry via $B+L$ violating sphaleron transitions.

In this paper we study the consequences of Dirac nature of neutrinos to a simultaneous solution of dark matter and baryon asymmetry of the Universe. We extend the SM by introducing a dark sector constituting of two vector-like Dirac fermions: ψ, a doublet under $SU(2)_L$, and χ, a singlet under $SU(2)_L$, as shown in the Fig. 1. See also refs. [21,22]. The dark sector is gauged under a $U(1)_D$ symmetry. An over all symmetry $U(1)_{B-L} \times Z_2$ is also imposed to ensure that the neutrinos are Dirac and the lightest particle χ in the dark sector is a candidate of dark matter, being odd under the Z_2 symmetry. A heavy scalar doublet X, odd under the discrete Z_2 symme-