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Leptogenesis in minimal left–right symmetric models

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Abstract

We analyze lepton asymmetry induced in the decay of right-handed neutrinos in a class of minimal left–right symmetric models. In these models, which assume low energy supersymmetry, the Dirac neutrino mass matrix is proportional to the charged lepton mass matrix. As a result, lepton asymmetry is calculable in terms of 9 parameters, all measurable in low energy neutrino experiments. By solving the Boltzmann equations numerically we show that adequate baryon asymmetry is generated in these models. This however places significant constraints on the light neutrino parameters. We find $\tan^2\theta_{12} \simeq m_1/m_2$ and $\theta_{13} = (0.01\text{–}0.07)$ for the neutrino oscillation angles, and $\beta \simeq \alpha + \pi/2$ for the Majorana phases.

1. Introduction

The discovery of neutrino flavor oscillations in solar, atmospheric, and reactor neutrino experiments [1] may have a profound impact on our understanding of the dynamics of the early universe. This is because such oscillations are feasible only if the neutrinos have small (sub-eV) masses, most naturally explained by the seesaw mechanism [2]. This assumes the existence of super-heavy right-handed neutrinos N_i (one per lepton family) with masses of order $(10^8\text{–}10^{14})$ GeV. The light neutrino masses are obtained from the matrix $M_\nu \simeq M_D M_R^{-1} M_D{}^T$ where M_D and M_R are respectively the Dirac and the heavy Majorana right-handed neutrino

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(r.h.n.) mass matrices. The decay of the lightest right-handed neutrino N_1 can generate naturally an excess of baryons over anti-baryons in the universe [3] consistent with cosmological observations. The baryon asymmetry parameter is an important cosmological observable constrained by big bang nucleosynthesis and determined recently with high precision by the WMAP experiment [4]:

$$\eta_B \equiv \frac{n_B}{n_\gamma} = \left(6.5^{+0.4}_{-0.3}\right) \times 10^{-10}. \tag{1}$$

The decay of N_1 can satisfy all three of the Sakharov conditions [5] needed for successful generation of η_B—it can occur out of thermal equilibrium, there is sufficient C and CP violation, and there is also baryon number violation. The last condition is met by combining lepton number violation in the Majorana masses of the right-handed neutrinos with $B + L$ violating interactions of the Standard Model arising through the electroweak sphaleron processes [6]. A compelling picture emerges, with the same mechanism explaining the small neutrino masses and the observed baryon asymmetry of the universe. η_B appears to be intimately connected to the observed neutrino masses and mixings.

A more careful examination of the seesaw structure would reveal that, although there is an underlying connection, the light neutrino mass and mixing parameters cannot determine the cosmological baryon asymmetry, when the seesaw mechanism is implemented in the context of the Standard Model (SM) gauge symmetry. It is easy to see this as follows. Without loss of generality one can work in a basis where the charged lepton mass matrix and the heavy right-handed neutrino Majorana mass matrix M_R are diagonal with real eigenvalues. The Dirac neutrino mass matrix would then be an arbitrary complex 3×3 matrix with 18 parameters (9 magnitudes and 9 phases). Three of the phase parameters can be removed by field redefinitions of the left-handed lepton doublets and the right-handed charged lepton singlets. The neutrino sector will then have 18 $(= 15 + 3)$ parameters. 9 combinations of these will determine the low energy observables (3 masses, 3 mixing angles and 3 phases), while the lepton asymmetry (and thus η_B) would depend on all 18 parameters, leaving it arbitrary.

In this paper we show that it is possible to quantitatively relate η_B to light neutrino mass and mixing parameters by implementing the seesaw mechanism in the context of a class of supersymmetric left–right models [7]. We note that unlike in the SM where the right-handed neutrinos appear as rather ad hoc additions, in the left–right symmetric models they are more natural as gauge invariance requires their existence. Supersymmetry has the well-known merit of solving the gauge hierarchy problem. With the assumption of a minimal Higgs sector, it turns out that these models predict the relation for the Dirac neutrino mass matrix

$$M_D = c \begin{pmatrix} m_e & 0 & 0 \\ 0 & m_\mu & 0 \\ 0 & 0 & m_\tau \end{pmatrix}, \tag{2}$$

where $c \simeq m_t/m_b$ is determined from the quark sector, leaving only the Majorana mass matrix M_R to be arbitrary. 3 phases in M_R can be removed, leaving a total of 9 parameters which determine both the low energy neutrino masses and mixings as well as the baryon asymmetry. It then becomes apparent that η_B is calculable in terms of the neutrino observables. There have been other attempts in the literature to relate leptogenesis with low energy observables [8,9]. Such attempts often make additional assumptions such as $M_D = M_{\rm up}$ (which may not be fully realistic), or specific textures for lepton mass matrices.

While a lot has been learned from experiments about the light neutrino masses and mixings, a lot remains to be learned. Our analysis shows that cosmology puts significant restrictions on