Low scale Higgs triplet soft leptogenesis

S Scopel
Korea Institute for Advanced Study, Seoul 130-722, Korea
E-mail: scopel@kias.re.kr

Abstract. In the minimal supersymmetric extension of the scalar triplet seesaw model for neutrino masses an additional source of CP violation can be provided by a phase in the trilinear soft-breaking terms. By explicitly solving the relevant Boltzmann equations including the gauge annihilation effect we show how in this scenario successful thermal leptogenesis can occur only for a mass of the decaying scalar triplet in the TeV scale. This opens up an interesting opportunity for testing the model at future colliders.

One way of understanding a tiny neutrino mass is to relate it with the vacuum expectation value of a Higgs scalar triplet, whose decay can also induce the cosmological baryon asymmetry in the Universe. This model, referred to as “type–II see–saw”, is nicely predictive, since the scalar triplet decay is completely determined by only one Yukawa matrix, which also induces neutrino masses. We consider here the minimal supersymmetric version of this scenario, which contains two Higgs scalar triplets, and in which CP phases in the soft supersymmetry–breaking terms can contribute to generate the lepton asymmetry. This scenario, called “soft leptogenesis” has been considered for the first time in Ref. [1].

We revisit here this scenario, by considering the full Boltzmann equations, including in a consistent way thermal masses and supersymmetry breaking effects. The details of the calculation outlined in the following, along with the relevant bibliography, may be found in Ref.[2].

In the supersymmetric form of the Higgs triplet model, one needs to introduce a vector-like pair of $\Delta = (\Delta^{++}, \Delta^{+}, \Delta^{0})$ and $\Delta^c = (\Delta^{c--}, \Delta^{c-}, \Delta^{c0})$ with hypercharge $Y = 1$ and $-1$ allowing for the renormalizable superpotential as follows:

$$W = hLL\Delta + \lambda_1 H^1 H^1 \Delta + \lambda_2 H^2 H^2 \Delta^c + M \Delta \Delta^c$$  

where $hLL\Delta$ contains the neutrino mass term, $h\nu\nu\Delta^0$. The soft supersymmetry breaking terms relevant for us are

$$-\mathcal{L}_{\text{soft}} = \{ hA_1 LL\Delta + \lambda_1 A_1 H^1 H^1 \Delta \\
+ \lambda_2 A_2 H^2 H^2 \Delta^c + BM \Delta \Delta^c + h.c. \\
+ m_{\Delta}^2 |\Delta|^2 + m_{\Delta^c}^2 |\Delta^c|^2 \}.$$  

Note that we have used the same capital letters to denote the superfields as well as their scalar components. We will consider the universal boundary condition of soft masses; $A_L = A_1 = A_2 = A$ and $m_\Delta = m_{\Delta^c} = m_0$. In the limit $M \gg m_0, A$, the Higgs triplet vacuum expectation

© 2006 IOP Publishing Ltd
value \(|\Delta^0| = \lambda_2 H_2^0 / M\) gives the neutrino mass

\[ m_\nu = 2h\lambda_2 \frac{v^2}{M} \]  

(3)

The mass matrix of the scalar triplets is diagonalized by \(\Delta = \frac{1}{\sqrt{2}}(\Delta_+ + \Delta_-)\), \(\Delta^c = \frac{1}{\sqrt{2}}(\Delta_+ - \Delta_-)\), where \(\Delta_\pm\) are the mass eigenstates with the mass-squared values, \(M_\pm^2 = M^2 + m_0^2 \pm BM\), and the mass-squared difference, \(\Delta M^2 = 2BM\). The heavy particles \(\Delta_\pm\) decay to the leptonic final state, \(LL, \bar{L}\bar{L}\), as well as by the effect of gauge annihilations, \(X\). The Hubble parameter \(H\) will use the Supersymmetric Standard Model value:

\[ g = \frac{\text{Supersymmetric Standard Model value}}{\text{Supersymmetric Standard Model value}} = 218.75. \]

The evolution of the abundance is determined by the decay and inverse decay processes, as well as by the effect of gauge annihilations, \(XX \to LL\). The CP asymmetry in the decay \(X \to j\) is defined as usual by \(\epsilon_j \equiv \Gamma(X \to j) - \Gamma(\bar{X} \to \bar{j}) / \Gamma_X\). In Eq. (4), \(K \equiv K_X / H_1\) with the Hubble parameter \(H_1 = 1.66\sqrt{s} / M^2 / m_P\) at the temperature \(T = M\), and \(B_j\) is the branching ratio of the decay \(X \to j\). For the relativistic degrees of freedom in thermal equilibrium \(g_\star\), we will use the Supersymmetric Standard Model value: \(g_\star = 228.75\).

In our model, the heavy particle \(X\) can be either of the six charged particles; \(X = \Delta_\pm^0, \Delta_\pm^\mp\). Each of them follows the first Boltzmann equation in Eq. (4) where \(\gamma_D\) and \(\gamma_A\) are given by

\[ \gamma_D = \frac{K_1(z)}{K_2(z)} \]  

(5)

\[ \gamma_A = \frac{\alpha^2 M}{\pi KH_1} \int_1^\infty dt \frac{K_1(2zt)}{K_2(z)} t^2 \beta(t) \sigma(t) \]  

(6)

with

\[ \sigma(t) = \frac{21}{2} \left[ 1 + \frac{1 - \beta(t)^2}{2} + \frac{1 - \beta(t)^4}{4\beta(t)} \ln \frac{1 - \beta(t)}{1 + \beta(t)} \right] + \frac{8}{3} \beta(t)^2 \]

and \(\beta(t) \equiv \sqrt{1 - t^{-2}}\). The function \(\gamma_D\) is the ratio of the modified Bessel functions of the first and second kind which as usual takes into account the decay and inverse decay effects in the Maxwell–Boltzmann limit. The function \(\gamma_A\) accounts for the annihilation cross-section of a triplet component \(X\) summing all the annihilation processes; \(XX' \to \text{Standard Model gauge bosons/gauginos and fermions/sfermions where } X' \text{ is some triplet component or its fermionic
Figure 1. Lepton asymmetry produced by triplet decay as a function of $z \equiv M/T$, for $M = 1, 2, 3, 4, 5$ TeV from top to bottom. Dotted and solid curves refer to $\text{Im}(A) = 1, 3$ TeV, respectively. The horizontal line shows the amount required to explain the observed baryon asymmetry after sphaleron conversion. The curves for the lepton asymmetry are plotted only for $z \leq z_{sp}$ where $z_{sp}$ corresponds to the decoupling temperature for sphaleron interactions.

For our calculation, we use the value of $\alpha_2 = 1/30 = 2\alpha_1$. In particular, we find that, for $M < 10^9$ GeV annihilations keep $X$’s in thermal equilibrium much longer than inverse decays, until $z \approx 20$, leading so to a substantial reduction of the final lepton asymmetry\[2\].

The results of our numerical calculation are shown in FIG. 1. The curves for the lepton asymmetry are plotted only for $z \leq z_{sp}$ where $z_{sp}$ corresponds to the decoupling temperature for sphaleron interactions. As shown in FIG. 1, the CP–violating contribution from the soft supersymmetry breaking term, $\delta \simeq |A|^2/M^2$, can strongly enhance the final lepton asymmetry.

As a result, it is evident that the required baryon asymmetry can be reached whenever $A$ and $M$ are in the multi-TeV region. In this case, the model predictions can be tested at future colliders by observing signals as clean as, for instance, the production and decay of doubly charged Higgs bosons.

Acknowledgments
Based on work done in collaboration with Eung Jin Chun.

References
[1] D’Ambrosio G, Hambye T, Hektor A, Raidal M and Rossi A 2004 Phys. Lett. B 604 199
[2] Chun E J and Scopel S 2005 Soft leptogenesis in Higgs triplet model Preprint hep-ph/0510170