

Dark Matter and Leptogenesis in the Inverse Seesaw

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We study a seesaw-type extension of the Standard Model in which the symmetry group is enlarged by a global $U(1)$. We introduce adequate scalar and fermion representations which naturally explain the smallness of neutrino masses. With the addition of a viable scalar Dark Matter candidate, an original and successful scenario of leptogenesis emerges.

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It is well known that leptogenesis in the type I seesaw cannot work at the TeV scale, unless a strong degeneracy exists among the heavy right-handed neutrinos that are introduced to explain the small neutrino masses, cf. eg. [1]. However, such a degeneracy is quite unnatural in the type I seesaw, and one rather advocates an inverse-seesaw mechanism [2], where the small mass splitting emerges from the breaking of an underlying symmetry, usually related to the accidental lepton number symmetry the Standard Model (SM) exhibits. In this proceeding, based on [3], we present a UV-completion of the inverse-seesaw, promoting the accidental symmetry to a global conserved charge and introducing the adequate Higgs representations accounting for non-zero neutrino masses. We further elaborate on this model by introducing a Dark Matter (DM) candidate, under the form of a scalar charged under the lepton (-like) charge, and whose very presence supplies an original scenario of leptogenesis, successful down to the TeV scale.

1. A UV-completion of the inverse-seesaw

We introduce a global $U(1)$ symmetry conserving a $B - \tilde{L}$ charge. B is the standard Baryon number, while \tilde{L} is the Lepton number extended to non-SM particles, thus quarks have charge $+1$ under this symmetry, while SM leptons have charge -1 . The SM Higgs boson H_1 has zero $B - \tilde{L}$ charge. In the inverse-seesaw mechanism, two right-handed neutrinos are introduced with opposite \tilde{L} charges $\tilde{L}(N_1) = 1 = -\tilde{L}(N_2)$. We conveniently form a Dirac spinor N_D with $\tilde{L}(N_D) = 1$ from both fields $N_D \equiv P_R N_1 + P_L N_2^c$, which couples to the SM-leptons through a Yukawa interaction $y_1 \overline{N_D} \tilde{H}_1^\dagger \ell + h.c.$ and receives a Dirac mass $M \overline{N_D} N_D$. As shown in [4] for example, with only this particle content, SM active-neutrinos are massless. The inverse-seesaw completion is obtained by introducing a scalar H_3 , singlet under the SM gauge group but with $\tilde{L}(H_3) = 2$, such that a Yukawa coupling can be written $\alpha H_3 \overline{N_D} N_D^c + h.c.$, yielding a Majorana mass once H_3 acquires a non-zero vacuum expectation value $\propto \alpha v_3 \overline{N_D} N_D^c$. Yet the model accounts only for one massive light neutrino [5], so we extend the particle content with a scalar doublet H_2 , with $\tilde{L}(H_2) = -2$. A Yukawa coupling $y_2 \overline{N_D} \tilde{H}_2^\dagger \ell + h.c.$ is formed, which provides a Dirac mass term after H_2 takes a non-zero vev. The light neutrino mass is given by

$$(m_\nu)^{ij} = -y_1^{\{i, y_2^j\}} \frac{v_1 v_2}{2M} + y_1^i y_1^j \alpha^* v_3 \frac{v_1^2}{2M^2} + y_2^i y_2^j \alpha v_3 \frac{v_2^2}{2M^2}, \quad v_i = \sqrt{2} \langle H_i \rangle. \quad (1.1)$$

As clear from the equation above, the introduction of H_2 is mandatory to obtain two-massive light neutrinos, as required by observations. Similarly $(y_1^e, y_1^\mu, y_1^\tau)$ and $(y_2^e, y_2^\mu, y_2^\tau)$ should not be aligned. As for the terms $\propto \alpha$, even if not necessary for neutrino masses, they are crucial for leptogenesis [3]. Furthermore, from the spontaneous breaking of the global $U(1)_{B-\tilde{L}}$ by the non-zero vev of H_2 and H_3 emerges a massless Goldstone boson, the Majoron, whose couplings to the SM particles are strongly constrained: this enforces a hierarchy among the Higgs vevs: $v_2 \ll v_{1,3}$, naturally realized in the model [3]. Therefore, the second term of eq.(1.1) dominates over the other terms, and the model effectively realizes an inverse-seesaw for neutrino masses.

2. A 2-step leptogenesis scenario

The realization described above explains neutrino masses, but yet fails to account for what makes the seesaw model so attractive: the explanation of the baryon asymmetry of the Universe via

the leptogenesis scenario [6]. To this end, we introduce a third right-handed neutrino, singlet under all conserved charges and of Majorana type, together with a complex scalar field S , a SM singlet but with $\tilde{L}(S) = 1$. The fermion singlet does not participate in neutrino mass generation, as no Higgs representation with $\tilde{L} = \pm 1$ are introduced. Several extra couplings are allowed by the symmetry of the model, among which the most relevant ones are a Yukawa coupling $g\bar{N}_3 N_D S^* + h.c.$ and a trilinear term $\mu'' S S H_3 + h.c.$. Through the exchange of H_3 , a CP asymmetry can be generated in N_3 decays, and a leptogenesis scenario arises. The generation of a baryon asymmetry proceeds in two stages:

- A first step in which asymmetries in N_D and S (and H_3) are created, by decays of N_3 , inverse decays, scatterings This stage is similar to the standard leptogenesis scenario in the type I seesaw.
- A second step during which the asymmetries in N_D and S are transferred to the SM leptons, through Yukawa couplings y_1 or y_2 driven interactions.

The lepton asymmetry produced in the second stage is reprocessed, partially, into a baryon asymmetry via sphaleron interactions. Note that the processes responsible for the two steps are/may be in thermal equilibrium at the same temperature, but the generation of an asymmetry in N_D is a required prior to the generation of a non-zero lepton asymmetry.

As in the standard leptogenesis scenario, the amount of N_D and S asymmetries produce during the first stage depends on the size of the CP asymmetry in N_3 decays and on the efficiency of leptogenesis, which results form a competition between production and depletion processes. In the limit where N_3 is much heavier than N_D , the CP asymmetry approximately equals

$$\varepsilon_{CP} \simeq -2 \times 10^{-6} \left(\frac{\mu''}{1 \text{ GeV}} \right) \left(\frac{10 \text{ TeV}}{M_3} \right) \text{Im}(\alpha), \quad (2.1)$$

where M_3 is the Majorana mass of N_3 . For non-suppressed α and ratio μ''/M_3 , the CP asymmetry is typically large enough. Concerning the efficiency of asymmetry production, several processes have to be considered. In a rough picture, decays and inverse decays dominate and values of $g \lesssim \text{few } 10^{-5}$ are required, for an optimal efficiency. The interesting point is that the CP asymmetry does not depend on the coupling g responsible of these washout. This is in sharp contrast with the leptogenesis scenario in the type I seesaw, where both depend on the neutrino Yukawa couplings.

The transfer of the asymmetry stored in N_D to the SM leptons occurs through the decays of N_D and through Higgs-mediated scatterings: all depend on the neutrino Yukawa couplings $y_{1,2}$. We show in [3] that when neutrino mass constraints are applied, the transfer is efficient and the leptonic asymmetry equals the asymmetry in N_D produced in the first stage. Thus basically, for neutrino Yukawa large enough, leptogenesis depends only on μ'' , α and g and is easily successful.

3. Dark Matter

The leptogenesis scenario reported above is only possible after the introduction of the scalar S , which constitutes a viable Dark Matter candidate. Actually, after the electroweak symmetry breaking, the complex S is split into two real fields, the lightest one being the DM. First, the

stability of this lightest state is insured by a discrete Z_2 symmetry remnant of the breaking of $U(1)_{B-\bar{L}}$. Second, the relic density of S easily satisfies observational requirements. Indeed, the scalar possesses several portal couplings to the H_i s, couplings which are basically unconstrained although entering in the DM mass: the annihilation cross-section of S is large enough, for a broad range of DM mass. Finally, S can scatter on nucleon via those Higgs portal couplings, and a signal in direct detection experiment can be expected in the full DM mass range, as we show in Figure 1 where we compare the model predictions for the spin-independent DM cross-section (blue dots) with the results of the XENON100 experiment [7] (red curve).

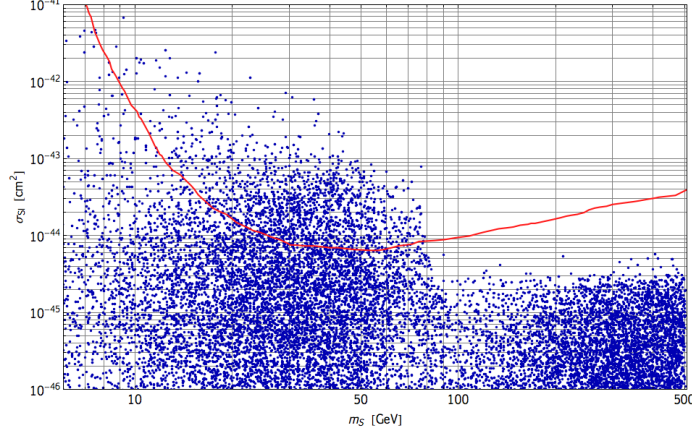


Figure 1: Spin-independent cross-section against Dark Matter mass.

4. Conclusion and Acknowledgments

In [3] we present a UV-completion of the inverse-seesaw model where the baryon asymmetry of the Universe is explained by an original leptogenesis mechanism which arises after the introduction of a scalar singlet field. This latter particle constitutes a viable Dark Matter candidate.

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References

- [1] S. Davidson, E. Nardi, Y. Nir, Phys. Rept. **466** (2008) 105-177.
- [2] R. N. Mohapatra and J. W. F. Valle, Phys. Rev. D **34** (1986) 1642.
- [3] F.X. Josse-Michaux, E. Molinaro, [arXiv:1108.0482 [hep-ph]].
- [4] J. Kersten, A. Y. Smirnov, Phys. Rev. **D76** (2007) 073005.
- [5] M. B. Gavela, T. Hambye, D. Hernandez and P. Hernandez, JHEP **0909** (2009) 038.
- [6] M. Fukugita and T. Yanagida, Phys. Lett. B **174** (1986) 45.
- [7] E. Aprile *et al.* [XENON100 Collaboration], arXiv:1104.2549 [astro-ph.CO].