Calculable neutrino masses in an Inverse See-Saw scenario and DM candidates

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Abstract. Within the supersymmetric inverse seesaw mechanism we provide a scenario where naturally small and calculable neutrino masses arise from a supersymmetry breaking renormalization-group-induced vacuum expectation value. In such a scenario the sneutrino can be the lightest supersymmetric particle potentially viable as WIMP dark matter.

1. Introduction
The solid experimental evidence for neutrino masses and oscillations [1], provide strong evidence for physics beyond the Standard Model. At the same time cosmological studies clearly show that a large fraction of the mass of the Universe is dark and must be non–baryonic.

The idea that the generation of neutrino masses may provide new insight on the nature of the dark matter is quite appealing.

Theory has no clue as to what causes the smallness of neutrino masses. It has become popular to ascribe it as an effect of a very high new physics scale in particular in the context of the so-called minimal type-I seesaw [2].

An alternative approach is the inverse seesaw mechanism [4, 5], which avoids introducing new states above the TeV scale. Neutrino masses arise well below the weak scale, thanks to a very small singlet mass term in whose presence lepton number is violated. In absence of the lepton number violating mass terms the symmetry of the theory increases and neutrinos are massless.

It has been shown that in a minimal supergravity (mSUGRA) [3] scheme where the smallness of neutrino masses is accounted for within the inverse seesaw mechanism the lightest supersymmetric particle is likely to be represented by the corresponding neutrino superpartner (sneutrino), instead of the lightest neutralino. Such a model naturally reconciles the small neutrino masses with the correct relic abundance of sneutrino dark matter and experimentally accessible direct detection rates.

The inverse see-saw scheme has not become as popular as the high-scale seesaw due to some discomfort in assuming by hand the smallness of an $SU(3) \times SU(2) \times U(1)$ invariant mass term.

Here we provide a plausible mechanism where the origin of such small scale would, in addition, find a natural dynamical explanation.

2. The model
The model is defined by the supermultiplets given in table 1, where $L$ denotes the global continuous lepton number and $R$ denotes the $R$-charge. We also impose a discrete $Z_3$ symmetry
that forbids bilinear couplings. The mechanism we develop requires the existence of a singlet sector, perhaps of stringy origin [6]. The required magnitude of the supersymmetric Higgs mass parameter arises from the expectation value of the extra singlet field present in the next-to-minimal supersymmetric standard model (NMSSM) [7], avoiding the so-called µ problem [8, 9], as recently advocated in Ref. [10]. The superpotential is given as

\[ W = y^u_{ij} \hat{L}_i \hat{H}_u \hat{E}_j^c + y^d_{ij} \hat{Q}_i \hat{H}_d \hat{D}_j^c + y^e_{ij} \hat{Q}_i \hat{H}_d \hat{E}_j^c + \lambda_1 \hat{\Phi} \hat{H}_u \hat{H}_d + \frac{1}{3!} \lambda_2 \hat{\Phi} \hat{\Phi} \hat{\Phi} \]

The corresponding soft supersymmetry breaking potential reads,

\[ V_{soft} = a^u_{ij} \hat{Q}_i \hat{H}_u e_j^c + a^d_{ij} \hat{Q}_i \hat{H}_d \hat{d}_j^c + a^e_{ij} \hat{L}_i \hat{H}_d \hat{e}_j^c + a_{\Phi H} \hat{\Phi} \hat{H}_u \hat{H}_d + \frac{1}{3!} a_{\Phi} \hat{\Phi} \hat{\Phi} + a^c_{ij} \hat{L}_i \hat{H}_u \hat{e}_j^c \]

From eq. (1) we see that neutrino masses are induced once the scalar singlet \( \Delta \) acquires a vev only in the presence of the trilinear soft term \( a_\Delta \). Thus, in the supersymmetric limit, neutrinos are massless. Assuming that all trilinear soft breaking terms vanish at the GUT scale \( M_0 \) implies that neutrinos are still massless even in the tree-level limit. However the breaking of supersymmetry due to the gaugino mass induces a small but non-vanishing \( a_\Delta \) through the RGEs. The singlet nature of the secluded sector protects \( a_\Delta \) that turns out to be naturally small.

3. The DM candidate
One can see that in most the cases the lightest sneutrino is a combination of the two singlet states \( \tilde{\nu}^c \) and \( \tilde{s} \). Since all trilinear couplings vanish at the GUT scale, the trilinears involving only gauge singlet fields run very slowly so \( v_\Delta \) is very small compared to the other vevs. Thus for the above choice the sneutrino mass matrix can be approximated as

\[
M_{\tilde{\nu}_i}^2 \sim \begin{pmatrix}
0 & 0 & 0 \\
0 & m_0^2 + \alpha_{\nu_i} v^2 & \pm \delta v^2 \\
0 & \pm \delta v^2 & m_0^2 + \beta_{\nu_i} v^2
\end{pmatrix}
\]

Table 1. Multiplet content of the model.
with $0 < \alpha_{ri}, \beta_{ri} \sim \mathcal{O}(1)$ while $\delta \sim \mathcal{O}(0.1)$ and where we have used $m_0^2 < 0$. Given that $m_L^2 > 0$, the natural lightest sneutrino is the CP even or CP odd combination of the singlet states.

As illustrated in Fig. 2, due to these mixing effects it is likely that the lightest supersymmetric particle is mainly a mixture of the singlet scalars $\tilde{\nu}$ and $\tilde{s}$, instead of the neutralino. In this sense, this model is similar to the scenario of Refs. [10, 11], since in both the right-handed sneutrino component couples directly to the NMSSM Higgs sector through the singlet $\Phi$. As shown there, this makes it possible to fulfil the WMAP result, thereby making the sneutrino a viable WIMP. A similar effect is expected in the present model, this time through the $\eta$ coupling in (1). Thus, the scheme proposed here opens yet new alternative ways to understand supersymmetric dark matter.

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