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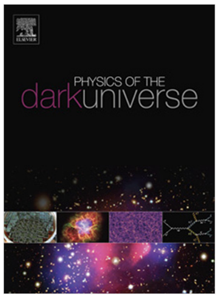

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Thermal production of light Dirac right-handed sneutrino dark matter

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We consider the production of right-handed (RH) sneutrino dark matter in a model of Dirac neutrino where neutrino Yukawa coupling constants are very small. Dark matter RH sneutrinos are produced by scatterings and decays of thermal particles in the early Universe without reaching thermal equilibrium due to the small Yukawa couplings. We show that not only decays of thermal particles but also the thermal scatterings can be a dominant source as well as non-thermal production in a scenario with light sneutrinos and charged sleptons while other supersymmetric particles are heavy. We also discuss the cosmological implications of this scenario.

PACS numbers:
Keywords: neutrino, dark matter

I. INTRODUCTION

Many experiments have established that neutrinos have non-vanishing masses, while the standard model (SM) was constructed assuming massless neutrinos. One of the simplest extension of the standard model for having massive neutrinos is to introduce the right-handed (RH) neutrinos and their Yukawa couplings. In the see-saw mechanism [1–3], heavy Majorana masses ($\gtrsim$ 100 GeV) of RH neutrinos are introduced and the light neutrino masses ($\lesssim$ eV) are obtained by the mass hierarchy. However, even without the see-saw mechanism, the light neutrino mass can be obtained from the Dirac mass, as in the same way of quarks and leptons, if the neutrino Yukawa coupling constants are very small of $\mathcal{O}(10^{-13}-10^{-12})$. After the electroweak symmetry breaking, the small Yukawa couplings give Dirac masses to the neutrinos.

In the theory of supersymmetry (SUSY), there exists the superpartner of the RH neutrinos, RH sneutrinos ($\tilde{N}$). Their masses come from the soft SUSY breaking and in many cases are of the order of the gravitino mass. Therefore, it is possible that the RH sneutrino is the lightest SUSY particle (LSP), stable due to the R-parity conservation and a good candidate for dark matter.

The possibility of the RH sneutrino as dark matter in the pure Dirac type neutrino and those productions through decays of various thermalized superparticles was pointed out by Asaka et al [4]. RH sneutrinos are not thermalized in the early Universe, because the interactions of RH sneutrinos are extremely weak. However, it has been shown that the right amount of dark matter can be produced in the parameter region where left-handed (LH) and RH sneutrinos are degenerate and sleptons are fairly light [4]. The dark matter abundance estimation was extended by including the non-thermal production of RH sneutrinos from decays of the next-to LSP (NLSP) after its freeze out [5, 6]. Such a long-lived NLSP scenario is constrained by the big bang nucleosynthesis (BBN) [7]. Possible collider signatures for the stau NLSP have been investigated [8, 9]. For the long-lived stau NLSP case, the lower mass bound for the stau (slepton) is reported as $\gtrsim$ 290 (380) GeV by the ATLAS [10] and $\gtrsim$ 340 GeV by the CMS [11, 12]. However this is not applicable to our scenario which we will describe below.

In this article, we consider the production of RH sneutrinos by scatterings in the thermal plazma. Usually and in previous studies [4–6], it has been considered that the scattering contribution is subdominant compared to the thermal production from decays or non-thermal production by decay of freeze out particles. However, we find that it can be comparable or even a dominant source, because there are huge number of scattering modes for the production of RH sneutrinos. Especially, such a dominant thermal production from scatterings realizes under the mass spectrum where the charged sleptons and sneutrinos are light and other SUSY particles are heavy, which is indicated by the observation of the SM-like Higgs boson with the mass of 125 GeV [13, 14]. In our analysis, for the illustration, we adopt the mass spectrum that one of the RH sneutrinos is the LSP, whose mass is close to those of the LH sneutrinos, LH charged sleptons and as light as around $\mathcal{O}(10^2)$ GeV and other SUSY particles are as heavy as about $1-5$ TeVexcept one light Higgsino-like neutralino around 700 GeV.

We also consider the cosmological issues in this scenario. Since the LH sneutrinos are slightly heavier than RH sneutrinos, LH sneutrinos may decay relatively late around or after the BBN, in which case strong constraint can be imposed on the model. Heavier RH sneutrinos may decay in the present Universe to the lightest RH sneutrinos with possible observational signals in the cosmic ray observation.

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