

Gravitino dark matter and a high reheating temperature

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Supersymmetry breaking mediated by gauge interactions is regarded an attractive option due to the lack of new sources of flavor changing neutral currents other than those already present in the Standard Model. In models with gauge mediated supersymmetry breaking (GMSB), the dark matter particle is the gravitino. It is produced both thermally in scatterings in the hot plasma and non-thermally from decays of the next to lightest supersymmetric particle (NLSP). If the NLSP is sufficiently abundant during Big Bang Nucleosynthesis (BBN), these decays can alter the abundances of light elements. This, in turn, gives constraints on the gravitino mass and, for the observed dark matter abundance, on the reheating temperature of the Universe. Since sufficiently high reheating temperature is crucial for thermal leptogenesis, one obtains constraints on viable models with GMSB, consistent with thermal leptogenesis. We study the interplay of these constraints within a recently introduced and interesting class of models with GMSB, known as models with general gauge mediation (GGM). We study the possibility that the NLSP is a stau or a sneutrino in these models. We determine whether it is possible to achieve ‘compressed’ spectra of supersymmetric particles in which gluino is not much heavier than the NLSP, which alleviates the constraints imposed by requiring successful thermal leptogenesis. We study regions of the parameter space of models with GGM and identify regions in which one achieves radiative breaking of electroweak symmetry, satisfies the higgs mass bounds, gravitinos make up the observed amount of dark matter and the reheating temperature is high enough for leptogenesis.

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The question of reconciling supersymmetric dark matter scenarios with the standard evolution of the Universe from very high temperatures was raised long ago [1] and addressed by many authors since. In scenarios with stable gravitinos, such as GMSB [2], it is generically difficult to reach high reheating temperature while maintaining consistency with the BBN bounds. In this case, the decay products of the NLSP threaten to alter BBN. Further, if the gravitino is the only constituent of dark matter, which is the case considered in this paper, its cosmological abundance is fixed to be $\Omega_{\tilde{G}} h^2 = 0.110 \pm 0.006$ [3]. Gravitinos can be thermally produced in the post-inflationary universe, with the abundance proportional to the reheating temperature, $\Omega_{\tilde{G}}^{\text{TP}} h^2 \propto T_{\text{R}}$, and also proportional to a factor depending on the precise superpartner spectrum. Requirements on $\Omega_{\tilde{G}}$ turn into requirements on T_{R} for a given superpartner spectrum. This, in turn, leads to strong limits on the reheating temperature T_{R} [4], which may be in conflict with the higher temperatures required for thermal leptogenesis [5]. The goal of this note is to identify the mass spectra that allow for maximal T_{R} and to describe models of GMSB predicting such mass pattern, following [6].

Very generally, the BBN bounds require that unstable relics previously present in the Universe, decay with lifetimes smaller than 100 s, unless the abundance of these particles is very small or only a tiny fraction of these particles decay with energetic hadrons in the final state [7]. Among the MSSM particles, the latter condition is satisfied by the lightest sneutrino or the lightest stau, hence its parameter space allows for $\tau_{\text{NLSP}} > 100 \text{ s}$. The cosmological constraints on late neutrino injection have been worked out [8], providing bounds on decaying sneutrino NLSP. It has been found that sneutrinos with masses smaller than about 330 GeV evade the BBN constraints. Such light sneutrinos are mostly constrained by the requirement that large scale structure formation is not too much affected by free-streaming gravitinos produced in the sneutrino decays [10]. Since the lighter the sneutrino the higher is the reachable reheating temperature, we shall restrict our considerations to a sneutrino in the mass range between 200 and 330 GeV. For stau NLSP with masses less than 1 TeV, the main BBN constraint is that of a correct primordial ${}^6\text{Li}$ abundance coming from its catalyzed production [9], ${}^6\text{Li}/\text{H} < 6 \times 10^{-11}$.

We are now in a position to calculate the maximal reheating temperature for the sneutrino and stau NLSP. We have $\Omega_{\tilde{G}} h^2 = \Omega_{\tilde{G}}^{\text{TP}} h^2 + (m_{3/2}/m_{\text{NLSP}}) \Omega_{\text{NLSP}} h^2$, where Ω_{NLSP} is the thermal relic abundance that the NLSP would have had, had it not decayed. We calculate the value of this parameter with the `micrOMEGAS.2.2` code [11], assuming that only the NLSP is light. $\Omega_{\tilde{G}}^{\text{TP}} h^2$ gives the abundance of thermally produced gravitinos [12], conveniently parametrized as [6]:

$$\Omega_{\tilde{G}}^{\text{TP}} h^2 = \left(\frac{T_{\text{R}}}{10^9 \text{ GeV}} \right) \left(\frac{m_{\text{NLSP}}}{300 \text{ GeV}} \right) \left[7.4 \times 10^{-6} \frac{m_{3/2}}{1 \text{ GeV}} + \frac{m_{\text{NLSP}}}{300 \text{ GeV}} \sum_r \gamma_r \left(\frac{M_r}{m_{\text{NLSP}}} \right)^2 \right], \quad (1)$$

where $r = 1, 2, 3$ corresponds to gauge groups $U(1)_Y$, $SU(2)_L$ and $SU(3)_C$, respectively, M_r denote physical gaugino masses and the coefficients γ_r depend on the ratios of the gauge couplings at the reheating scale and the scale of the physical gaugino masses. The values of γ_r can be evaluated for $T_{\text{R}} = 10^9 (10^7) \text{ GeV}$ as $\gamma_3 = 0.48 - 0.56 (0.62 - 0.74)$, $\gamma_2 = 0.57 (0.54)$, $\gamma_1 = 0.22 (0.17)$, where the range for γ_3 corresponds to the gluino masses ranging from 200 to 900 GeV. Obviously, for fixed value of $\Omega_{\tilde{G}}^{\text{TP}} h^2$ dominating $\Omega_{\tilde{G}} h^2$, the reheating temperature is maximal if the masses of the NLSP and of the three gauginos are degenerate at the low scale (see also [13]).

In general gauge mediation (GGM) [14], the soft masses at the gauge mediation scale Q are

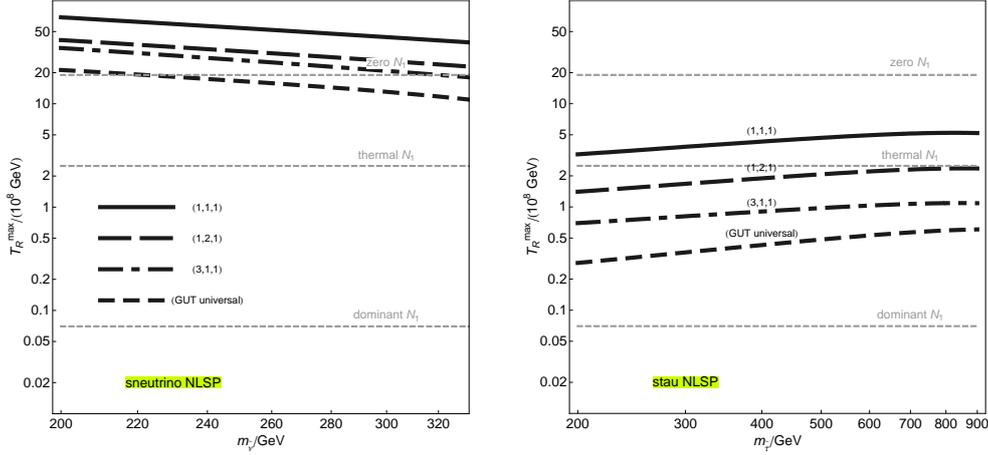


Figure 1: The maximal reheating temperature for the sneutrino (left) and the stau NLSP (right) for four mass patterns of the gauginos at the low-scale $(M_3/m_{\text{NLSP}}, M_2/m_{\text{NLSP}}, M_1/m_{\text{NLSP}}) = (1, 1, 1), (1, 2, 1), (3, 1, 1),$ and (GUT universal). They correspond, respectively, to solid, dash-dotted, long-dashed, and short-dashed lines. ‘Dominant’, ‘zero’ and ‘thermal’ N_1 lines correspond to lower limits of T_R needed for leptogenesis given various initial conditions, see [5].

given by $\tilde{M}_r = (g_r^2/(16\pi^2))\Lambda_r$ and $\tilde{m}_s^2 = 2\sum_{r=1}^3 (g_r^2/(16\pi^2))^2 C_r^{(s)} \kappa_r \Lambda_r^2$. The *a priori* unknown degrees of freedom in the model are parametrized by Λ_r and κ_r .

To a good approximation we can identify the lighter stau with the right stau. Imposing the bound $m_E^2 < M_1^2$, we find $\kappa_1 < 0.089$ for $Q = 10^{15}$ GeV or, equivalently, $\tilde{m}_E^2 < 0.1\tilde{M}_1^2$ at the high scale. Since in gauge mediation models $\tilde{m}_E^2 > 0$, we also have $M_1^2 > m_E^2 > 0.6M_1^2$. Thus, the low energy masses of stau and bino are almost degenerate, as a result of the RG evolution itself. With $Q = 10^{14}$ GeV, we obtain a slightly weaker bound $\kappa_1 < 0.13$. In the other case, $m_L^2 < m_E^2$, which can give sneutrino NLSP, the following three conditions are relevant for constraining the parameter space: $m_L^2 < \{m_E^2, M_1^2, M_2^2\}$, giving the bounds $\kappa_1 < 0.24 - 1.8\kappa_2$ and $\kappa_2 < 0.09$. In particular, these bounds imply that $\kappa_1 < 0.24$, and that the bino and wino physical masses must be in the range $0.6M_1 < M_2 < 1.2M_1$. For sufficiently large left-right mass splitting compared to the left-right mass mixing term of the slepton mass matrix we get a sneutrino NLSP. With $\mu = 1000$ GeV and $\tan\beta = 10$ this possibility requires a minimal splitting between $\sqrt{m_E^2}$ and $\sqrt{m_L^2}$ of about 100 GeV.

By tuning Λ_2 and Λ_3 against Λ_1 , we can achieve the gluino and wino masses degenerate with the sneutrino/stau NLSP mass. Then we have freedom to choose κ_3 and the absolute scale of the GGM model given by Λ_1 to ensure that the electroweak symmetry is broken, the Higgsino is heavier than the NLSP and that the stops are heavy enough to satisfy the Higgs boson mass bound.

To summarize, having identified the mass patterns of the MSSM that allow for maximal reheating temperature, we found the parameter sets of the GGM models leading to such mass patterns. Interestingly, these parameter sets arise in rather simple models, with messenger belonging to $\mathbf{40} + \mathbf{40}$, $3 \times \mathbf{24}$ or $\mathbf{75}$ representations of the unified gauge group $SU(5)$.

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