

Revisiting No-Scale Supergravity Inspired Scenarios

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We consider no-scale supergravity inspired scenarios, emphasizing the possible dynamical determination of the soft supersymmetry-breaking parameters as triggered by the radiative corrections that lift an essentially flat tree-level potential in the hidden sector. We (re)emphasize the important role played by the scale-dependent vacuum energy contribution to the effective potential for the occurrence of consistent no-scale minima. The most relevant input parameters are introduced as B_0 (the soft breaking mixing Higgs parameter) and η_0 (the cosmological constant value at high energy) instead of $m_{1/2}$ and $\tan\beta$, the latter being determined through a (generalized) potential minimization at electroweak scales. We examine the theoretical and phenomenological viability of such a mechanism when confronted with up-to-date calculations of the low energy sparticle spectrum and with present constraints from the LHC and other observables. The tight dark matter relic density constraint for a neutralino LSP scenario can be considerably relaxed for a gravitino LSP scenario possible in this framework.

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1. Introduction

No-scale supergravity models [1, 2, 3] are a specific set of supergravity models, in which the vanishing of the tree-level potential in the hidden sector direction can be automatic for an appropriately chosen form of the Kähler potential. Moreover, the value of the gravitino mass $m_{3/2}$ can be fixed dynamically by (non-gravitational) radiative correction stabilization, and is related to other soft SUSY-breaking parameters. This no-scale mechanism has been known for a long time, but the complexity of a full minimization of the effective potential lead in the early days to consider only specific approximations. More recently the strict no-scale boundary conditions $m_0 = A_0 = 0$ have often been studied for their phenomenological consequences but without specifying a precise link with the above-mentioned scalar potential minimization. Modern MSSM spectrum calculation tools allow to incorporate the full one-loop as well as dominant two-loop contributions to the effective scalar potential and other important radiative corrections. We will take advantage of this to go further in the study of no-scale models [4], implementing the minimization mechanism within SuSpect [5]. In a generalized no-scale inspired framework, it first requires the definition of the soft parameters at the GUT scale

$$B_0 = b_0 m_{1/2}, \quad m_0 = x_0 m_{1/2}, \quad A_0 = a_0 m_{1/2}; \quad (1.1)$$

where the gaugino mass is the unique scale parameter, and the strict no-scale corresponds to $b_0 = x_0 = a_0 = 0$. Notice that the usual $\tan\beta$ input is replaced by B_0 , the former being consistently derived at the electroweak scale. In addition to this usual parameter set, we will have to consider a new one, in the form of a boundary condition η_0 for a vacuum energy term, following [6].

2. Renormalization Group invariant effective potential

The vacuum energy term η_0 finds its roots in renormalization group (RG) invariance properties of the effective potential [7]. Adding one-loop contributions to the tree-level potential already ensures a more stable physical spectrum, but without the vacuum energy contribution the effective potential is not RG-invariant. In particular in the no-scale approach one is interested in the overall shape of the potential, and obviously a meaningful minimum is expected to be scale-independent, as much as possible perturbatively. The (one-loop) RG-invariant potential reads:

$$V_{full} \equiv V_{tree}(Q) + V_{1-loop}(Q) + \tilde{\eta}(Q)m_{1/2}^4 \quad (2.1)$$

where as usual the one-loop contribution is expressed in terms of (field dependent) eigenmasses as

$$V_{1-loop}(Q) = \frac{1}{64\pi^2} \sum_{alln} (-1)^{2n} M_n^4(H_u, H_d) \left(\ln \frac{M_n^2(H_u, H_d)}{Q^2} - \frac{3}{2} \right) \quad (2.2)$$

and in Eq. (2.1) the vacuum energy term is conveniently scaled by $m_{1/2}$ without much loss of generality. $\eta(Q)$ runs from η_0 at GUT scale to η_{EW} at EW scale. We have checked that this term is not only crucial for RG-invariance and stability of the potential and corresponding physical minimum, but its contribution is also strongly correlated with the position of the minimum, and the corresponding value of the gaugino mass $m_{1/2}$.

3. The minimization procedure

The generalized no-scale electroweak minimization implies, in addition to the two usual EW minimizations $\frac{\partial V_{full}}{\partial v_i} = 0$, $i = u, d$, an extra minimization in the gaugino direction: $\frac{\partial V_{full}}{\partial m_{1/2}} = 0$. This will dynamically determine the soft parameters if all related to $m_{1/2}$ as in Eq. (1.1). Assuming furthermore $\mu \sim m_{1/2}$, the latter minimization takes the convenient form [6, 4]

$$V_{full}(m_{1/2}) + \frac{1}{128\pi^2} \sum_n (-1)^{2n} M_n^4(m_{1/2}) + \frac{1}{4} m_{1/2}^5 \frac{d\tilde{\eta}_0}{dm_{1/2}} = 0 \quad (3.1)$$

where the last term is non-vanishing only in case $\tilde{\eta}_0$ may be a non-trivial function of $m_{1/2}$. Upon minimizing the potential, care is to be taken when handling some of the physical constraints. Typically the right m_Z mass constraint, $m_Z^2 = \frac{v^2}{2}(g'^2 + g^2)$, and the pole-to-running mass relations (mostly in the top quark sector due to strong dependence on the top quark Yukawa coupling), $m_{top}^{pole} = Y_t(Q)v_u(Q)(1 + \delta_y^{RC}(Q) + \dots)$, should be imposed only *after* the global minimum in the three directions $v_u, v_d, m_{1/2}$ has been found. This implies deviations of a few percent in the $m_{1/2}$ minima values when taken into account properly [4].

4. No-scale favored regions

On phenomenological grounds, the no-scale mechanism generally favours a charged (mostly $\tilde{\tau}$) LSP for $m_0 = 0$ or small enough. This is not a problem as it is natural to consider the gravitino as the true LSP within this framework. Current sparticle mass limits from the LHC [8] exclude small $m_{1/2} \lesssim 300 - 350$ GeV values. Other indirect constraints, such as $B \rightarrow s\gamma$ measurements, LEP Higgs mass bounds, etc, can be accommodated for sufficiently large $m_{1/2}$. In our case, $m_{1/2}$ limits translate into bounds on η_0 values, favouring lower values $\eta_0 \lesssim 8 - 10$ (depending on other parameters, B_0 etc) [4]. But it is still possible to have viable parameter regions with non-trivial $m_{1/2}$ minima, including even a decoupled supersymmetric spectrum with a light SM-like Higgs, when $\eta_0 \simeq 0$.

5. Gravitino dark-matter

For scenarios with a gravitino LSP (with stau as NLSP), all supersymmetric particles decay to the NLSP well before the latter has decayed to a gravitino, because all interactions to the gravitino are suppressed by the Planck mass. We first compute, using micrOMEGAs 2.0 [9], the relic density $\Omega_{NLSP} h^2$ the NLSP would have if it did not decay to the gravitino. Then assuming that each NLSP with mass m_{NLSP} decays to one gravitino, leads to the non-thermal contribution to the gravitino relic density

$$\Omega_{3/2}^{NTP} h^2 = \frac{m_{3/2}}{m_{NLSP}} \Omega_{NLSP} h^2 \quad (5.1)$$

with $h = 0.73_{-0.03}^{+0.04}$ the Hubble constant. The gravitino can also be produced during reheating after inflation. The gravitino relic density from such thermal production, $\Omega_{3/2}^{TP} h^2$, is essentially controlled by the reheat temperature T_R (see e.g [10]). Comparing the total gravitino relic density $\Omega_{3/2}^{TP} h^2 + \Omega_{3/2}^{NTP} h^2$, to WMAP constraints[11], will constrain T_R together with the no-scale

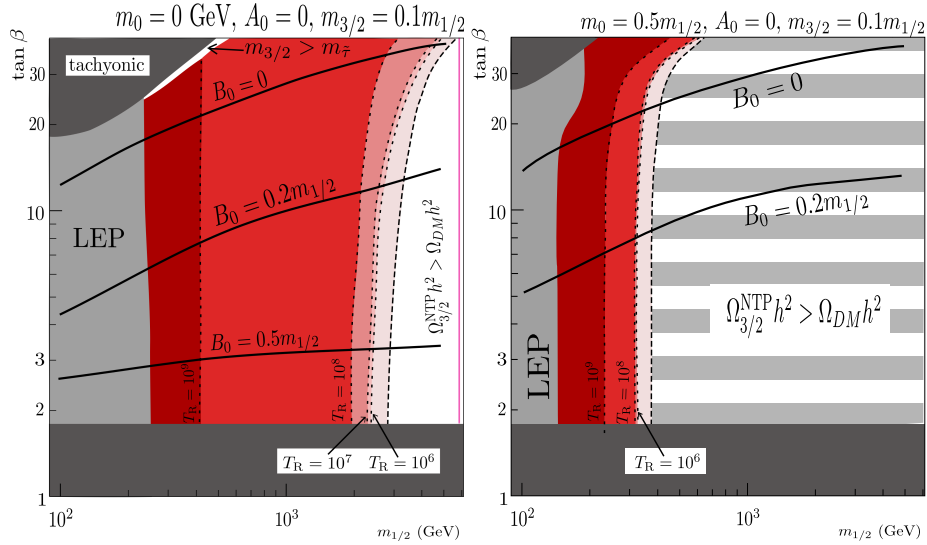


Figure 1: Gravitino LSP and relic density

parameter space. We illustrate two representative cases in the $(\tan\beta, m_{1/2})$ plane, one for the strict no-scale scenario ($m_0 = A_0 = 0$), and another less stringent scenario where the neutralino has some room as the LSP (though only for rather low $m_{1/2}$). One recovers consistency with the WMAP relic density constraint in a large part of the parameter space, provided that T_R is sufficiently large, $T_R \gtrsim 10^6$ GeV. In particular even for the strict no-scale model $B_0 = m_0 = A_0 = 0$ there is a range for $m_{1/2} \sim 400 - 800$ GeV, $\tan\beta \sim 20 - 25$ compatible with all present constraints, provided that the reheat temperature is $10^8 - 10^9$ GeV.

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