Dark Energy density in Split SUSY models inspired by degenerate vacua

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MPP inspired SUGRA models

In general the vacuum energy density in $(N=1)$ supergravity (SUGRA) models is huge and negative. The situation changes dramatically in no-scale supergravity where the invariance of the Lagrangian under imaginary translations and dilatations results in the vanishing of the vacuum energy density. Unfortunately these global symmetries also protect supersymmetry which has to be broken in any phenomenologically acceptable theory.

The breakdown of dilatation invariance does not necessarily result in a non–zero vacuum energy density [1]. This happens if the dilatation invariance is broken in the superpotential of the hidden sector only. The hidden sector of the simplest SUGRA model of this type involves two singlet superfields, T and z that transform differently under dilatations

$$T \to \alpha^2 T\,, \qquad\qquad z \to \alpha z\,.$$

The invariance under the global symmetry transformations constrains the Kähler potential and superpotential of the hidden sector, which can be written in the following form [1]:

$$\begin{aligned}\hat{K} &= -3\ln\left[T+\overline{T}-|z|^2\right],\\ \hat{W}(z) &= \kappa\left(z^3+\mu_0 z^2+\textstyle\sum_{n=4}^{\infty} c_n z^n\right).\end{aligned} \tag{1}$$

Here $\frac{M_{Pl}}{\sqrt{8\pi}}=1$. The bilinear mass term for the superfield z and the higher order terms $c_n z^n$ in the superpotential $\hat{W}(z)$ spoil the dilatation invariance. However the SUGRA scalar potential of the hidden sector remains positive definite

$$V(T,\,z) = \frac{1}{3(T+\overline{T}-|z|^2)^2}\left|\frac{\partial \hat{W}(z)}{\partial z}\right|^2, \tag{2}$$

so that the vacuum energy density vanishes near its global minima. When $c_n=0$, the scalar potential (2) has two extremum points at $z=0$ and $z=-\frac{2\mu_0}{3}$. In the first vacuum, where $z=-\frac{2\mu_0}{3}$, local supersymmetry is broken and the gravitino gains a non–zero mass. In the second minimum, the vacuum expectation value of the superfield z and the gravitino mass vanish.

Thus the considered breakdown of dilatation invariance leads to a natural realisation of the multiple point principle (MPP). *The MPP postulates the existence of many phases allowed by a given theory having the same energy density.* Successful application of the MPP to $(N=1)$ supergravity requires us to assume the existence of a vacuum in which the low–energy limit of the considered theory is described by a pure SUSY model in flat Minkowski space. According to the MPP this vacuum and the physical one in which we live must be degenerate. This normally requires an extra fine-tuning. In the SUGRA model considered above the MPP conditions are fulfilled automatically without any extra fine-tuning at the tree–level. We now assume the existence of a phenomenologically viable model of this type.

The value of the dark energy density

Since the vacuum energy density of supersymmetric states in flat Minkowski space is zero and all vacua in the MPP inspired SUGRA models are degenerate, the cosmological constant problem is thereby solved to first approximation by our assumption. However non–perturbative effects in the observable sector can give rise to the breakdown of SUSY in the second vacuum (phase). Here we assume that

$$f_a(T,\,z) \simeq const\,.$$

Due to the mild dependence of $f_a(T,\,z)$ on T and z the gauginos of mass M_a are much lighter than the scalar particles of mass $m_\alpha \sim M_S$. Such a hierarchical structure of the particle spectrum appears in Split SUSY models.

When $f_a(T,\,z)\simeq const$, the gauge couplings at high energies are almost identical in both vacua. Then the scale Λ_{SQCD}, where the supersymmetric QCD interactions become strong in the second vacuum, is given by

$$\Lambda_{SQCD} = M_S \exp\left[\frac{2\pi}{b_3\alpha_3^{(2)}(M_S)}\right], \tag{3}$$

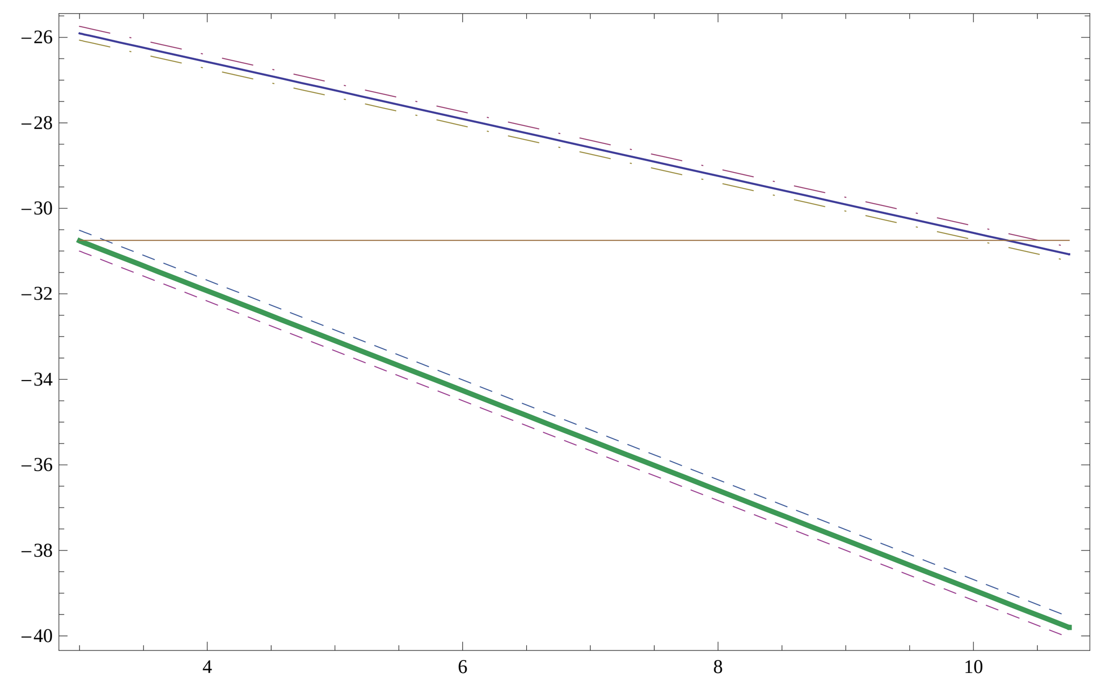
$$\frac{1}{\alpha_3^{(2)}(M_S)} = \frac{1}{\alpha_3^{(1)}(M_Z)} - \frac{\tilde{b}_3}{4\pi}\ln\frac{M_g^2}{M_Z^2} - \frac{b_3'}{4\pi}\ln\frac{M_S^2}{M_g^2},$$

where $\alpha_3^{(1)}$ and $\alpha_3^{(2)}$ are the values of the strong gauge couplings in the physical and second vacua respectively, M_g is the gluino mass, while $\tilde{b}_3=-7$, $b_3=-3$ and $b_3'=-5$ are the beta functions for $\alpha_3^{(1)}(\mu)$ in the SM, MSSM and Split SUSY scenario respectively.

At the scale Λ_{SQCD} the t–quark Yukawa coupling is of the same order of magnitude as the strong gauge coupling. So large Yukawa coupling may result in the formation of a quark condensate that breaks SUSY, inducing a positive value for the cosmological constant $\Lambda \simeq \Lambda_{SQCD}^4$.

Then the MPP assumption implies that the physical phase has the same energy density as the phase where supersymmetry breakdown takes place in the observable sector. From Fig. 1 one can see that the measured value of the cosmological constant is reproduced when $\Lambda_{SQCD} = 10^{-31}M_{Pl} \simeq 10^{-3}$ eV which is attained for $M_S \sim 10^{10}$ GeV. This value of M_S varies from $2\cdot 10^9$ GeV up to $3\cdot 10^{10}$ GeV for $\alpha_3(M_Z)=0.116-0.121$ and $M_g = 500-2500$ GeV [2].

$\log[\Lambda_{SQCD}/M_{Pl}]$



$\log[M_S]$

Fig. 1: The value of $\log[\Lambda_{SQCD}/M_{Pl}]$ versus $\log M_S$ for $M_q = M_g = 500$ GeV. The thin and thick solid lines correspond to the Split SUSY scenarios with the pure MSSM particle content and the MSSM particle content supplemented by $5+\bar{5}$ multiplets respectively. The horizontal line represents the observed value of $\Lambda^{1/4}$. The SUSY breaking scale M_S is given in GeV.

The obtained prediction for M_S can be tested. A striking feature of the Split SUSY model is the extremely long lifetime of the gluino. In the considered case the gluino decays through a virtual squark to $q\bar{q}+\chi_1^0$. The large mass of the squarks then implies a long lifetime for the gluino

$$\tau \sim 8\left(\frac{M_S}{10^9\,\text{GeV}}\right)^4\left(\frac{1\,\text{TeV}}{M_g}\right)^5 s. \tag{4}$$

If M_S varies from $2\cdot 10^9$ GeV ($M_g = 2500$ GeV) to $3\cdot 10^{10}$ GeV ($M_g=500$ GeV) the corresponding gluino lifetime changes from 1 sec. to $2\cdot 10^8$ sec. (1000 years) [2].

The observed value of the cosmological constant can also be reproduced for $M_S \simeq 1$ TeV, if the MSSM particle content is supplemented by an additional pair of $5+\bar{5}$ supermultiplets [1].

References

[1] C. Froggatt, R. Nevzorov and H. B. Nielsen, Nucl. Phys. B **743** (2006) 133 [hep-ph/0511259].

[2] C. Froggatt, R. Nevzorov and H. B. Nielsen, arXiv:1103.2146 [hep-ph].