Smallness of the cosmological constant and the multiple point principle

Roman Nevzorov

Glasgow University

in collaboration with C.D.Froggatt and H.B.Nielsen

Outline

- Introduction
- No–scale supergravity
- MPP inspired SUGRA model
- Cosmological constant in the MPP inspired SUGRA models
- Conclusions

Based on:

C. D. Froggatt, R. Nevzorov and H. B. Nielsen, Nucl. Phys. B 743 (2006) 133;

C. D. Froggatt, L. V. Laperashvili, R. Nevzorov and H. B. Nielsen, Phys. Atom. Nucl. 67 (2004) 582 [arXiv:hep-ph/0310127].

Introduction

- Astrophysical and cosmological observations indicate that there is a tiny energy density spread all over the Universe

$$\rho_\Lambda \sim 10^{-123} M_{Pl}^4 \sim 10^{-55} M_Z^4 \sim (10^{-3}\, eV)^4 \,.$$

- At the same time the presence of a gluon condensate in the vacuum is expected to contribute an energy density

$$\rho_{QCD} \sim \Lambda_{QCD}^4 \simeq 10^{-74} M_{Pl}^4 \,.$$

- In the SM a much larger contribution must come from the EW symmetry breaking

$$\rho_{EW} \sim v^4 \simeq 10^{-62} M_{Pl}^4 \,.$$

- But the contribution of zero–modes is expected to push ρ_Λ up to M_{Pl}^4.

- Because of the enormous cancellation between the contributions of different condensates to ρ_Λ the smallness of the cosmological constant should be regarded as a fine–tuning problem.
- An exact global supersymmetry ensures zero value for the vacuum energy density.
- But supersymmetry must be broken.
- The breakdown of SUSY induces a huge and positive contribution to ρ_Λ

$$\rho_\Lambda \sim \Lambda_{SUSY}^4 \,,$$

  where Λ_{SUSY} is a SUSY breaking scale.
- The non–observation of squarks and sleptons implies that $\Lambda_{SUSY} >> 100\,$GeV.

No–scale supergravity

- The scalar potential in $(N=1)$ SUGRA models is specified in terms of the Kähler function

$$G(\phi_M, \phi^*_M) = K(\phi_M, \phi^*_M) + \ln|W(\phi_M)|^2\,.$$

- The SUGRA scalar potential is given by

$$V(\phi_M, \phi^*_M) = \sum_{M,\,\bar N} e^G \left(G_M G^{M\bar N} G_{\bar N} - 3\right) + \frac{1}{2}\sum_a (D^a)^2\,,$$

$$G_M \equiv \partial G/\partial\phi_M\,, \quad G_{\bar M} \equiv \partial G/\partial\phi^*_M\,, \quad G^{M\bar N} = G^{-1}_{\bar N M}\,,$$

$$D^a = g_a \sum_{i,\,j} \left(G_i T^a_{ij}\phi_j\right)\,.$$

- SUGRA models include singlet fields which form hidden sector that gives rise to the breaking of local SUSY and induces non-zero gravitino mass

$$m_{3/2} =< e^{G/2} >$$

- In SUGRA models $\rho_\Lambda \sim < e^{G/2} > \sim -m^2_{3/2} M^2_{Pl}$.

- The Lagrangian of the simplest no–scale SUGRA model is invariant under imaginary translations

$$T \to T + i\beta \,, \qquad\qquad \varphi_\sigma \to \varphi_\sigma$$

and dilatations

$$T \to \alpha^2 T \,, \qquad\qquad \varphi_\sigma \to \alpha\,\varphi_\sigma \,.$$

- The invariance under imaginary translations and dilatations constrain Kähler function

$$K = -3\ln\left[T + \overline{T} - \sum_\sigma \zeta_\sigma |\varphi_\sigma|^2\right] , \qquad W = \sum_{\sigma,\lambda,\gamma} \frac{1}{6} Y_{\sigma\lambda\gamma}\, \varphi_\sigma\varphi_\lambda\varphi_\gamma \,.$$

- Global symmetries ensure the vanishing of vacuum energy density in the no–scale SUGRA models.
- These symmetries also preserve supersymmetry in all vacua.

MPP inspired SUGRA model

- In order to achieve the appropriate breakdown of local supersymmetry dilatation invariance must be broken.
- Let us consider SUGRA model with two hidden sector fields that transform differently under the dilatations

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

and imaginary translations

$$T \to T + i\beta\,, \qquad\qquad z \to z\,.$$

- We allow the breakdown of dilatation invariance in the superpotential of the hidden sector

$$W(z,\,\varphi_\alpha) = \varkappa\left(z^3 + \mu_0 z^2 + \sum_{n=4}^{\infty} c_n z^n\right) + \sum_{\sigma,\lambda,\gamma} \frac{1}{6} Y_{\sigma\lambda\gamma}\varphi_\sigma\varphi_\lambda\varphi_\gamma\,,$$

where μ_0 and $c_n \sim 1$.

- We also assume that the dilatation invariance is broken in the K$\ddot{a}$hler potential of the observable sector

$$K=-3\ln\left[T+\overline{T}-|z|^2-\sum_{\sigma}\zeta_{\sigma}|\varphi_{\sigma}|^2\right]+\sum_{\sigma,\lambda}\left(\frac{\eta_{\sigma\lambda}}{2}\,\varphi_{\sigma}\,\varphi_{\lambda}+h.c.\right)+\sum_{\sigma}\xi_{\sigma}|\varphi_{\sigma}|^2\,.$$

- Such breakdown of global symmetry preserves a zero value of the energy density in all vacua.
- The scalar potential of the hidden sector takes a form

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

- When $c_n=0$ this SUGRA scalar potential has two minima with zero vacuum energy density

$$z=0\,,\qquad\qquad z=-\frac{2\mu_0}{3}\,.$$

- In the vacuum where $z=-2\mu_0/3$ local supersymmetry is broken so that gravitino and all scalar particles get non–zero masses:

$$m_{3/2}=\frac{4\varkappa\mu_0^3}{27\left\langle\left(T+\overline{T}-\frac{4\mu_0^2}{9}\right)^{3/2}\right\rangle}\,,\qquad m_\sigma\sim\frac{m_{3/2}\xi_\sigma}{\zeta_\sigma}\,.$$

- In the vacuum with $z=0$ local SUSY remains intact and the low–energy limit of this theory is described by a pure SUSY model in flat Minkowski space.
- The vanishing of ρ_Λ can be considered as a result of degeneracy of all possible vacua in the considered theory, one of which is supersymmetric with $<W>=0$.
- The presence of degenerate vacua with broken and unbroken local supersymmetry leads to the natural realisation of the multiple point principle (MPP).

- MPP postulates the existence of the maximal number of phases with the same energy density which are allowed by a given theory.
- Being applied to supergravity MPP implies the existence of a phase with global SUSY in flat Minkowski space.
- Such vacuum is realised only if SUGRA scalar potential has a minimum where the following conditions are satisfied

$$\left\langle W(z_i^0) \right\rangle = \left\langle \frac{\partial W(z_i)}{\partial z_j} \right\rangle_{z_i = z_i^0} = 0\,,$$

  that requires an extra fine-tuning in general.
- In the considered no–scale SUGRA models the MPP conditions are fulfilled without any extra fine-tuning.

Cosmological constant

- According to MPP the physical and supersymmetric vacua have the same energy density.
- Since the vacuum energy density of supersymmetric states in flat Minkowski space is zero ρ_Λ in the physical vacuum vanishes in the leading approximation.
- However non–perturbative effects in the observable sector may lead to the breakdown of SUSY in the supersymmetric phase.
  - The supersymmetry breakdown can be caused by the strong interactions that give rise to a non–zero positive value for the cosmological constant

$$\rho_\Lambda \simeq \Lambda_{SQCD}^4 \,.$$

  - In particular, large top quark Yukawa coupling may induce t–quark condensate that breaks SUSY.

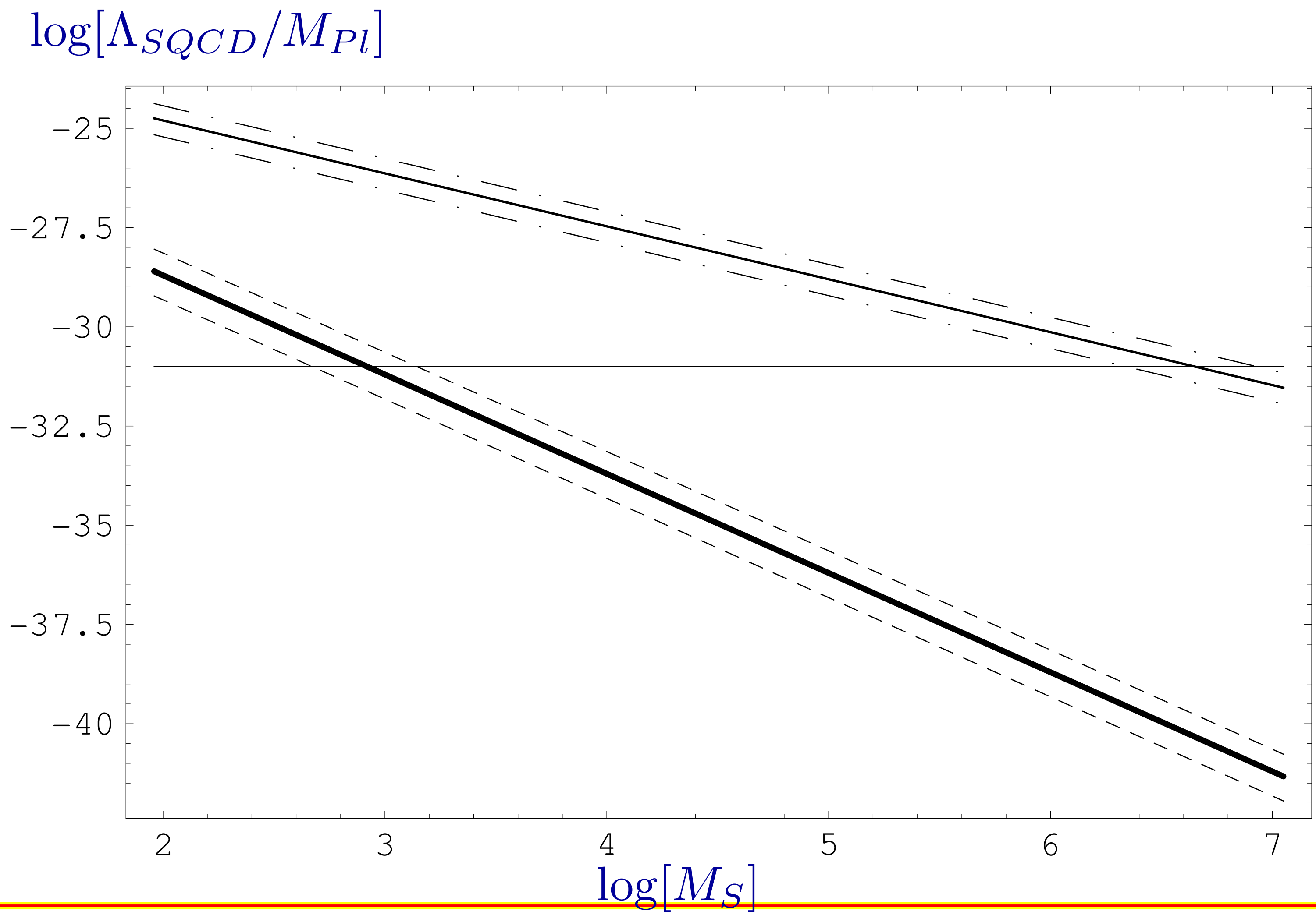
- We assume that at high energy scale the gauge and Yukawa couplings are the same in both vacua.
- In the supersymmetric vacuum the QCD interaction becomes strong at

$$\Lambda_{SQCD} = M_S \exp\left[\frac{2\pi}{b_3 \alpha_3^{(2)}(M_S)}\right], \quad \frac{1}{\alpha_3^{(2)}(M_S)} = \frac{1}{\alpha_3^{(1)}(M_Z)} - \frac{\tilde{b}_3}{4\pi} \ln \frac{M_S^2}{M_Z^2},$$

where M_S is a SUSY breaking scale and $\tilde{b}_3 = -7$.

- In the MSSM ($b_3 = -3$) the measured value of ρ_Λ is reproduced for $M_S = 10^3 - 10^4$ TeV.
- If the MSSM particle content is supplemented by a pair of $5 + \bar{5}$ multiplets ($b_3 = -2$) then the observed value of ρ_Λ can be obtained even for $M_S \simeq 1$ TeV.

- In the physical vacuum extra particles gain masses $\sim M_S$ due to the presence of $\eta(5 \cdot \overline{5})$ term in $K(\phi_M, \phi_M^*)$.



Conclusions

- In no–scale supergravity global symmetries protect local supersymmetry and a zero value for the cosmological constant.
- The breakdown of these symmetries that ensures the vanishing of ρ_Λ near the physical vacuum leads to the natural realization of the multiple point principle (MPP).
  - MPP requires the degeneracy of all global vacua.
  - MPP also predicts the existence of a supersymmetric phase in flat Minkowski space that results in the vanishing of ρ_Λ to first approximation.
- Non–perturbative effects can give rise to the breakdown of SUSY in the supersymmetric vacuum inducing tiny and positive value of ρ_Λ, i.e.

$$\rho_\Lambda \ll 10^{-100} M_{Pl}^4 \,.$$