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Kähler Manifolds with Vanishing Chiral Potential *

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Abstract

We study the general class of superpotentials on Kähler manifolds that give rise to Vanishing Chiral Potential ($\mathcal{VCP}$) at the tree level. We study properties of these potentials in the presence of gaugino condensation and show that it can lead to reasonable hierarchies in the scalar sector.

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N=1 Supergravity theories have been very successful in providing the framework for the unification of gravity with the other gauge interactions of the strong, electromagnetic and weak forces[1]. This unification has been achieved through the introduction of local supersymmetry to the theory and thus brings into the family of particles a vast number of supersymmetric partners, including the gravitinos, the gauginos, etc. Despite the vastly increased number of symmetries, however, the theory still has a large degree of arbitrariness, in the choice of the Kähler potential, the superpotential and in the choice of the gauge kinetic modulator function, $f_{\alpha\beta}$[2].

In this paper, we consider a scheme that would help reduce the arbitrariness in the supergravity theory. For a theory with only gauge singlet chiral multiplets, it has already been noted[3,4] that a class of Kähler manifolds exists which lead to a cosmologically flat chiral potential, where $V_{\rm chiral}$ is given by

$$V_{\rm chiral} = -e^{-G}[3 + G_k (G^{-1})^k_l G^l] \tag{1}$$

As has already been shown[4,5], the vanishing of the tree level chiral potential results from a hidden symmetry of the Kähler manifold. Since there is no D-term in this case, the full scalar potential actually vanishes. The advantage of such a theory would then be that quantum loop corrections are called upon to generate the effective scalar potential, and the parameters of the scalar potential are now calculable, rather than put in by hand at the tree level.

In the presence of gauge non-singlet multiplets, however, there is always a D-term in the full scalar potential which cannot be made to vanish by the hidden symmetry of the Kähler manifold.

$$V_{\rm scalar} = V_{\rm chiral} + D\text{term} \tag{2}$$

Faced with this, one approach has been to give up on the requirement of a vanishing chiral potential ($\mathcal{VCP}$) and simply make use of Kähler manifolds that lead to a zero cosmological constant. Another approach that we will pursue in this paper is to continue with the requirement of $\mathcal{VCP}$ [6] on the grounds that $\mathcal{VCP}$ puts needed restrictions on the Kähler manifold. These restrictions can go a long way towards reducing the arbitrariness of the theory. Once G and f are given, the D term no longer has any degree of freedom.

Consider the class of Kähler potentials of the type[7,8]

$$G = \alpha \ln(S + S^*) + \beta \ln(T + T^* - 2|\phi|^2) - \ln|W|^2 \qquad (3)$$

where S and T are gauge singlets and ϕ are the matter multiplets transforming under some irrep of the gauge group.

It can then be shown that $\mathcal{VCP}$ results from the following two conditions being satisfied simultaneously

(i)$\alpha + \beta = 3$,

and

(ii)W, the superpotential, given up to an overall constant by any one of the following cases:

$$1, S^\alpha, S^\alpha T^\beta, T^\beta, 0.$$

Here both α and β are required to be positive by unitarity.

As mentioned earlier, we need quantum loop corrections to produce the effective scalar potential that would govern the hierarchy of masses in the usual low energy phenomenology. In general, for arbitrary $f_{\alpha\beta}$, this requires a one loop field theoretic calculation that would fully exploit the hidden symmetries of the Kähler manifold. Work in this direction is currently in progress.

Part of the quantum loop correction can already be obtained from a study of gaugino condensation in the hidden sector[9,10,11,12]. Strictly speaking, the gaugino condensation mechanism is complicated here by the presence of a four-fermion gaugino interaction that apparently spoils the renormalizability. This term is suppressed however by the Planck mass scale, and if we view it as a cutoff in the theory, it becomes reasonable to consider only the usual hidden sector gauge interactions in the condensate.

Gaugino condensation is expected to occur at some scale, μ_c, where the hidden gauge sector coupling becomes confining. By renormalization group arguments, this is given by

$$\mu_c = M e^{-1/b g_0^2} \qquad (4)$$

with $g^2(\mathrm{M}) = g_0^2$, and M is here taken to be the Planck mass. As is well-known, the gauge kinetic modulator, $f_{\alpha\beta}$, acquires a vacuum expectation value at M and can be identified by a scaling argument with $1/g_0^2$[10,11]. For a choice of $f_{\alpha\beta} = \delta_{\alpha\beta} S$, this fixes $\langle S \rangle = 1/(4\pi\alpha_{GUT})$.

In the presence of the hidden sector gauge interactions, the effective supergravity Lagrangian involving all the matter as well as the hidden sector gaugino fields begins to acquire new condensate-induced terms. In particular, gaugino bilinear operators can disappear into the vacuum through the vacuum expectation terms (σ, τ = Dirac indices, α, β = gauge indices)

$$\lambda^{\alpha}_{\mathrm{L}\sigma}\lambda^{\beta}_{\mathrm{L}\tau} \rightarrow \lambda^{\alpha}_{\mathrm{L}\sigma}\lambda^{\beta}_{\mathrm{L}\tau} - \frac{1}{2}R(\mathrm{P}_{+}\mathrm{C})_{\tau\sigma}\delta^{\alpha\beta} \tag{5}$$

$$\overline{\lambda_{\mathrm{L}\sigma}}^{\alpha}\overline{\lambda_{\mathrm{L}\tau}}^{\beta} \rightarrow \overline{\lambda_{\mathrm{L}\sigma}}^{\alpha}\overline{\lambda_{\mathrm{L}\tau}}^{\beta} + \frac{1}{2}R(\mathrm{P}_{-}\mathrm{C}^{\dagger})_{\tau\sigma}\delta^{\alpha\beta} \tag{6}$$

where R is the corresponding vacuum expectation value chosen to be real, $\mathrm{P}_{+}, \mathrm{P}_{-}$ are chirality projection operators, and C is the charge conjugation matrix.

Performing these shifts in the N=1 supergravity Lagrangian of Cremmer *et al.*, we find additional contributions to the scalar potential, and to the mass terms for the gaugino, gravitino and chiral fermions. For the scalar potential these are found to be

$$\begin{aligned}\delta\mathcal{L}_{\mathrm{scalar}} = \frac{1}{16}(G^{-1})^{k}_{l} f^{*}_{\alpha\beta,k} f^{,l}_{\gamma\delta} R^{\alpha\beta} R^{\gamma\delta} \\ + \frac{1}{4} e^{-G/2} G^{l} (G^{-1})^{k}_{l} f^{*}_{\alpha\beta,k} R^{\alpha\beta} + \frac{1}{4} e^{-G/2} G_{k} (G^{-1})^{k}_{l} f^{,l}_{\alpha\beta} R^{\alpha\beta} \\ + \frac{3}{8}(Ref_{\alpha\gamma})(Ref_{\beta\delta}) R^{\alpha\beta} R^{\gamma\delta}\end{aligned} \tag{7}$$

while for the fermion mass terms[1] we have

$$\begin{aligned}\delta\mathcal{L}_{\mathrm{m,F}} = \{\frac{1}{4}(Ref_{\alpha\beta}) R^{\alpha\beta} \overline{\Psi}_{\mu}\sigma_{\mu\nu}\Psi_{\nu} \\ + [\frac{1}{16}(G^{-1})^{k}_{l} f^{*}_{\alpha\beta,k} f^{,l}_{\gamma\delta} R^{\gamma\delta} + \frac{3}{8}(Ref_{\alpha\gamma})(Ref_{\beta\delta}) R^{\gamma\delta}] \overline{\lambda_{\mathrm{L}}}^{\alpha} \lambda^{\beta}_{\mathrm{R}} \\ + \frac{1}{16} R^{\gamma\delta} (-4G^{ij}_{k}(G^{-1})^{k}_{l} f^{,l}_{\gamma\delta} + 4f^{,ij}_{\gamma\delta} - Ref^{-1}_{\alpha\beta} f^{,i}_{\alpha\gamma} f^{,j}_{\beta\delta}) \overline{\chi_{i\mathrm{R}}} \chi_{j\mathrm{L}} \\ + \mathrm{h.c.}\}\end{aligned} \tag{8}$$

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[1] In addition to the terms listed in eq. (8), one also expects to get a further contribution to the gaugino mass coming from renormalisation group improved dynamical symmetry breaking mechanisms[13]

In eq 8 above, we have included fermion mass terms that arise from the Fierz transformation of the current-current 4-fermion gaugino interaction as well as the gaugino-gravitino interaction terms. As a result of these Fierz terms, the observable sector (E(6)) gauginos will acquire a mass through the hidden-sector gaugino condensation.

The new terms in the effective scalar potential due to gaugino condensation do not respect the $\mathcal{VCP}$ requirement. Maintaining a zero cosmological constant for this induced potential leads to an interesting scenario for the hierarchy of masses in the theory. For example, for a $\mathcal{VCP}$ Kähler potential of the type

$$G = \alpha \ln(S + S^*) + \beta \ln(T + T^* - 2|\phi|^2) - \ln|S^\alpha T^\beta|^2 \tag{9}$$

and for a gauge kinetic modulator, $f_{\alpha\beta} = \delta_{\alpha\beta} S$ we find that the vacuum expectation value for the T field can be made to be as low as 10^2 GeV for a $\beta \sim .11$, with the vev for the S field at .8 times the Planck mass, corresponding to an α_{GUT} at Planck scale of 1/10[15,16,17,18,19] and a b for the supersymmetric E(8) with only one gauge multiplet of $90/(8\pi^2)$.

We remark that of the five cases listed above for the $\mathcal{VCP}$ Kähler potentials only those whose superpotential depend on T will give rise to this highly desirable scenario. The others necessarily give rise to a vev for T that is of order of the Planck scale and is therefore less interesting from a phenomenological point of view.

As a consequence of eq.(5,6), the on-shell gravitino mass will receive two contributions, one from the vev of the Kähler potential and another from the gaugino condensate, and is thus given by

$$m_{3/2} = \langle e^{-G/2} + \frac{1}{4}(Ref_{\alpha\beta}) R \delta^{\alpha\beta} \rangle \tag{10}$$

For the type of scenarios considered above, the gravitino mass in our effective N=1 supergravity Lagrangian tends to be of order Planck's mass. It may also be of interest to note that if we do not insist on the $\mathcal{VCP}$ scenario then the possibility exists to have a vanishing gravitino mass by a cancellation between the Kähler and the gaugino condensate contributions.

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