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One-loop Effective Potential from Compactified Superstring Models*

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This contribution is a report on a recent determination [1] of the one loop effective potential from the effective tree Lagrangian in models obtained from compactification [2] of the zero-slope limit of superstring [3] theories, both with and without induced terms [4] conjectured to arise from non-perturbative effects in a hidden sector of the theory.

To put our results in perspective, let me briefly recall the background phenomenological context. The construction [5,6] of effective tree Lagrangians for $N = 1$ supergravity coupled to matter made possible the realization [7] of viable models with softly broken supersymmetry at low energies. Typically some scalar field acquires a vacuum expectation value (vev) $\langle Z_0 \rangle \sim m_P \equiv \kappa^{-1} = (8\pi G_N)^{-1/2} = 2.4 \times 10^{18}$ GeV, that induces a gravitino mass $m_{\tilde{G}} \neq 0$, thus breaking supersymmetry. An effective renormalizable theory at the scale m_P is defined by making an appropriate shift in the scalar field $Z_0 \rightarrow Z_0' = Z_0 - \langle Z_0 \rangle$ and then letting $\kappa \rightarrow 0$. The low energy theory is then obtained by using standard renormalization group methods [7]. In general scalar fields acquire positive squared masses [5,8] $m_S^2 = 0(m_{\tilde{G}}^2)$ at the Planck scale, and one arranges [7] Yukawa couplings such that the squared masses of appropriate scalar doublets of $SU(2)_L$ are driven negative by renormalization effects at a scale $0(m_W^2) \equiv 0(m_S^2) \equiv 0(m_{\tilde{G}}^2)$ thus triggering electroweak symmetry breaking. It was subsequently pointed out [9] that symmetries of the tree potential may protect scalar masses at tree level and beyond (but apparently at most to two loops), allowing $m_S << m_{\tilde{G}}$. Such a scenario was explicitly realized in "no-scale" models [10] that have the properties that at tree level *a)* $m_S = 0$ for all gauge non-singlets, *b)* there is no cosmological constant and *c)* the vev of one scalar field (t), and therefore the value of $m_{\tilde{G}}$, is left unspecified.

Under the assumption that supersymmetry survives in four dimensions, compatification [11] of 6 of the 10 dimensions of the superstring on a Calabi-Yau manifold K_6 led to the construction [2] of a class of effective scalar models that are a particular variant of the "no-scale" models, including an additional scalar field (s) whose vev is unspecified at tree level. Superstring theories exist [3,12] for the gauge groups $SO(32)$ and $E_8 \times E_8'$. Viable phenomenology seems possible only for the latter case, where E_8 breaks in four dimensions to an E_6 grand unified theory and E_8' (or some subgroup thereof) describes a hidden sector that is assumed to be pure supersymmetric Yang-Mills, with no chiral non-singlet multiplets. The

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hidden sector becomes strongly interacting at some scale $\mu_c < m_P$, a gaugino condensate forms inducing [4] a non-trival super-potential for the scalar field s that determines its vev and breaks supersymmetry. It is assumed that other non-perturbative effects conspire to cancel the cosmological constant induced by the gaugino condensate, in which case the vev of t and the value of $m_{\tilde{G}}$ remain undetermined at tree level.

Models such as these, where a large vev is determined by radiative corrections, require an accurate determination of those corrections near the Planck scale. We therefore do not truncate the tree Lagrangian to an effective renormalizable one by dropping $O(\kappa)$ terms, but instead evaluate the full one-loop effective potential in a form that is explicitly invariant under scalar field redefinition and preserves the non-linear symmetries of the tree Lagrangian. Thus from the point of view of a four-dimensional field theory our result is valid at arbitrarily high scales, although there may be other $O(\kappa)$ effects, *e.g.* from higher string modes, that we neglect. We make no *a priori* assumption on the gauge groups that survive in four dimensions, nor on the spectrum of gauge non-singlet chiral multiplets.

Our results are: [1,13] 1. In the absence of condensate effects (*i.e.* at scales $\mu \gg \mu_c$), the vacuum structure of the tree potential is preserved by the one-loop radiative-corrections. 2. In the presence of supersymmetry breaking condensate effects at tree level, the gauge non-singlet scalars remain massless at the one-loop level. 3. In this case the vev of Re t and therefore $m_{\tilde{G}}$ are determined at one loop. Specifically we find that $m_{\tilde{G}}$, the condensate scale μ_c and the grand unification scale $m_{\rm GUT}$ must all lie within a few orders of the Planck scale; $m_{\tilde{G}} \lesssim \mu_c \lesssim m_{\rm GUT}$ with

$$\begin{aligned} 1.5\times 10^{-3} &\lesssim m_{\tilde{G}}/m_P \lesssim 0.1, \\ 0.05 &\lesssim \mu_c/m_P \lesssim 0.55. \end{aligned} \tag{1}$$

This result is very insensitive to the regularization prescription used, and relatively insensitive to the choice of input parameters: the gauge coupling $\alpha_{\rm GUT}$ and the β-function parameter b_0 that is determined from the structure of the surviving hidden gauge group in four dimensions. These parameters are however restricted by the requirement $m_{\rm GUT} < m_P$ that we imposed for consistency; specifically we found

$$1/44 \lesssim \alpha_{\rm GUT} \lesssim \frac{1}{8}, \quad b_0 \gtrsim 0.2. \tag{2}$$

The parameter μ_c enters the one-loop potential explicitly as the cufoff above which the condensate effects are negligible, and b_0 also appears as an explicit parameter in the effective superpotential that determines Re s at tree level. In addition the above parameters enter implicitly through the relations [4]:

$$\begin{aligned} \alpha_{\rm GUT}^{-1} &= \langle 4\pi {\rm Re}\, s\rangle, \\ m_P^2 m_{\rm GUT}^{-2} &= \langle {\rm Re}\, s {\rm Re}\, t\rangle, \\ m_P^2 \mu_c^{-2} &= \langle {\rm Re}\, s {\rm Re}\, t \exp({\rm Re}\, s/b_0)\rangle. \end{aligned} \tag{3}$$

Imposing that these relations be consistent with the values of Re s and Re t obtained by minimizing the corrected potential, together with the condition $m_{GUT} < m_P$, gives the constraints (1) and (2).

It should be remarked that the only fermions that acquire masses at tree level are the gravitino and the chiral partners of s and t. As a result the scalar field t and the terms quadratic in the gauge non-singlet fields ϕ_i appear only in the combination $2{\rm Re}\, t - \kappa\phi_i\phi^i$ in the one-loop effective potential, so the coefficient of $\phi_i\phi^i$ is just $\partial V^{eff}/\partial({\rm Re}\, t) = 0$ at the minimum. In particular the gauginos remain massless at tree level; unless there are further subtle cancellations they should acquire masses at one loop, and one would expect [9] gauge non-singlet scalars to acquire masses of order $\mu_c m_{\tilde{G}}/16\pi^2 m_P$, which appears unacceptably large, but this remains to be explicitly established.

A possible caveat in the above analysis is that we find a non-vanishing cosmological constant at one loop. If, as has been recently claimed [14], the non-linear symmetry of the model assures a vanishing cosmological constant to all orders, this term should be cancelled by another contribution that we have overlooked. However it seems unlikely that such a term would affect the vanishing of the scalar masses related to the $SU(N+1)/U(N+1)$ symmetry of scalar kinetic energy term, nor change substantially the orders of magnitude found for the scales of the theory, Eqs. 1.

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