PHENOMENOLOGICAL ASPECTS OF HETERO TIC EFFECTIVE MODELS AT ONE LOOP

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We provide a study of the phenomenology of orbifold compactifications of the heterotic string within the context of supergravity effective theories. Our investigation focuses on those models where the soft Lagrangian is dominated by loop contributions to the various soft supersymmetry breaking parameters. We consider the pattern of masses that are governed by these soft terms and investigate the implications of certain indirect constraints on supersymmetric models, such as flavor-changing neutral currents, the anomalous magnetic moment of the muon and the density of thermal relic neutralinos.

1 Introduction

One of the most crucial and difficult tasks of string phenomenologists is now to make, and keep, contact between the high energy theory, and the low energy world. For that, we need to consider a superstring theory which yields in four dimensions, the Standard Model gauge group, three generations of quarks, and a consistent mechanism of SUSY breaking. Our analysis have relies on orbifold compactifications of the heterotic string within the context of supergravity effective theories. More specifically, we concentrate on those models where the action is dominated by one loop order contributions to soft breaking terms. Recently, all one loop order contributions have been calculated. The key point of such models is the non universality of supersymmetry breaking term which is a consequence of the beta–function appearing in the superconformal anomalies. This non universality gives a specific phenomenology in the gaugino and the scalar sectors, modifying the predictions coming from Msugra. In fact, these string-motivated models show new behavior that interpolates between the phenomenology of unified supergravity models (Msugra) and models dominated by the superconformal anomalies (AMSB). The constraints arising from accelerator physics, and dark matter aspects have been already studied. It becomes interesting now, to see in which sense experimental limits on supersymmetric particles will be able to bring us informations, or even to rule out some of these models.
2 Theoretical Framework

Our phenomenological study is based on orbifold compactifications of the weakly–coupled heterotic string, where we distinguish two regimes. In the first one, SUSY breaking is driven by the compactification moduli $T$, whose vacuum expectation values determine the size of the compact manifold. In the second one, it is the dilaton field $S$, whose vacuum expectation value determines the magnitude of the (unified) coupling constant $g_{\text{STR}}$ at the string scale, that transmits, via its auxiliary fields, SUSY breaking. We work in the context of models in which string nonperturbative corrections to the Kahler potential act to stabilize the dilaton in the presence of gaugino condensation. The origins of breaking terms are diverse. Some coming from the superconformal anomalies are non–universal (proportional to the beta–function of the $SU(3) \times SU(2) \times U(1)$ groups) some are independent of the gauge group considered (Green–Schwarz counterterm, $vev$ of the condensate). This interplay between universality and non–universality gives a rich new phenomenology, and indicates new trends in the search of supersymmetric particles in accelerator or astroparticle physics.

2.1 The moduli dominated scenario

In the moduli dominated scenario, the supersymmetric susy breaking terms can be written

\[ M_a = \frac{g_a^2(\mu)}{2} \left\{ 2 \left[ \frac{\delta_{\alpha\beta}}{16\pi^2} + b_a \right] G_2(t, \bar{t}) F^T + \frac{2}{3} b_a M \right\}, \tag{2.1} \]

\[ A_{ijk} = -\frac{1}{3} \gamma_i \bar{M} - p \gamma_i G_2(t, \bar{t}) F + \text{cyclic}(ijk), \tag{2.2} \]

\[ M_i^2 = (1 - p) \gamma_i |M|^2 \tag{2.3} \]

where $b_a$ is the one loop beta–function coefficient of the $SU(3) \times SU(2) \times U(1)$ gauge coupling $g_a=1,2,3$. The field $M$ is the auxiliary field of the supergravity multiplet related to the gravitino mass by

\[ M_{3/2} = -\frac{1}{3} \langle \bar{M} \rangle. \tag{2.4} \]

We clearly see in these formulae the mixing between universal term and non–universal ones. Moreover, scalar mass terms are coming with a loop suppression factor $\gamma_i$, and the gaugino mass breaking terms have a universal compensation coming from the Green–Schwarz counterterm (appearing in
order to cancel anomalies) that can give high value to the chargino or neutralino masses. To sum up, this regime gives light scalars and relatively heavy gauginos, whose nature depends completely on the value of $\delta_{GS}$.

### 2.2 The dilaton dominated scenario

In this region of parameter space, we can express the soft SUSY breaking terms as

$$M_a = \frac{g_a^2(\mu)}{2} \left\{ \frac{2}{3} b_a M_T + [1 - 2b'_a k_s] F^S \right\}$$  \hspace{1cm} (2.5)$$

$$A_{ijk} = -\frac{k_s}{3} F^S - \frac{1}{3} \gamma_i M + \tilde{\gamma}_i F^S \left\{ \ln(\mu^2_r / \mu^2_R) - p \ln [(t + \bar{t})|\eta(t)|^4] \right\} + (ijk)$$  \hspace{1cm} (2.6)$$

$$M_i^2 = \frac{|M|^2}{9} \left[ 1 + \gamma_i - \left( \sum_a \gamma_a^g - 2 \sum_{j,k} \gamma_i^j \right) \left( \ln(\mu^2_r / \mu^2_R) - p \ln [(t + \bar{t})|\eta(t)|^4] \right) \right]$$

$$+ \left\{ \frac{1}{6} \frac{\tilde{\gamma}_i M F^S}{M_3} + \text{h.c.} \right\},$$  \hspace{1cm} (2.7)$$

with

$$F^S = 3 \frac{b_+}{1 - \frac{4}{3} b_+ K_s} M_{3/2}.$$  \hspace{1cm} (2.8)$$

with $b_+$ being the largest beta–function coefficient among the condensing gauge groups of the hidden sector, $k_s$ the derivative in $S$ of the Khaler potential and $p_i$ the Pauli–Villars weights of the regulator fields.

The phenomenology of the dilaton dominated scenario is completely different from the moduli dominated one. If we look at (2.5) and (2.6), it is clear that we are in a domain of heavy squarks and sleptons (of the order of the gravitino scale) and light gaugino masses, directed by the dilaton auxiliary field $\nu'$. Indeed, the beta–functions $b_a$ are of the order of $10^{-2}$, which will not be competitive compared to the $F$ term of the dilaton in (2.5). In fact, if we look more clearly at (2.8), for not so big values of $b_+$, we can consider that $F^S$ has a linear evolution as a function of $b_+$. Increasing $b_+$ means approaching the universal case for the gaugino sector (and the scalar one, driven by $M_{3/2}$).

Even within the restricted context of the weakly-coupled heterotic string compactified on an orbifold, the phenomenology of such supergravity effective theories is far richer and varied than that of the standard “minimal”
Figure 1. Constraints on the moduli-dominated parameter space for $\tan \beta = 5$ (left) and $\tan \beta = 35$ (right) with $p = 0$ and $\langle \text{Re} \, t \rangle = 2.0$. Constraints on the $(M_{3/2}, \delta_{GS})$ plane are given for $\mu > 0$. The dark shaded regions on the left have a stau LSP. For $\tan \beta = 5$ the region labeled “Ω” has the cosmologically preferred relic density of neutralinos. The exclusion contours are due to (from bottom right to upper left) CCB vacua, the chargino mass, too large SUSY contributions to $(g_\mu - 2)$, the Higgs mass limit and too large a $b \to s\gamma$ rate.

Figure 2. Constraints on the dilaton-dominated parameter space for $\tan \beta = 5$ (left) and $\tan \beta = 35$ (right). Constraints on the $(M_{3/2}, b_+)$ plane are given for $\mu > 0$. 

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supergravity approach. While our current indirect knowledge on the nature of supersymmetry already constrains these models significantly, there still exist large regions of parameter space for all the cases studied here – even for low values of $\tan \beta$. We anticipate that future measurements of, or limits on, superpartner masses and kinematic distributions will constrain the parameters of these models further. So will future cosmological or astrophysical measurements. In fact, this type of measurement forms a useful complement that will be crucial in unraveling the nature of supersymmetry breaking and its mediation in such models.

Parameters that are related to the orbifold can have a large impact on these broad features. This is a welcome result – implying that experimental data can indeed probe the nature of the underlying theory within a class of models. For example, in cases where supersymmetry breaking is transmitted predominantly by the moduli associated with compactification the relative sign of terms proportional to their auxiliary field and that of the conformal anomaly can in principle be measured. This parameter, in turn, is related to the spontaneous breakdown of modular invariance that may occur in such models.

Future studies of such string-based models should focus on extending this initial survey to true collider signatures in both hadron and lepton machines as well as computing event rates for astrophysical processes.

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