

Astroparticle and Collider Physics as Complementary Sources for the Study of String Motivated Supergravity Models

Y. Mambrini

LPT, 91400 Orsay, France – DESY, 22607 Hamburg, Germany

We provide a study of the phenomenology of heterotic orbifold compactifications scenarios 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, giving a mixed anomaly-gravity mediation model. We consider the pattern of masses that are governed by these soft terms and investigate the implications of certain indirect constraints on supersymmetric models. In this framework, we point out how the complementarity between direct and indirect detection of a neutralino Dark Matter, and future accelerator prospects can reduce considerably the parameter space of such models

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 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 [1]. 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 [2]. The prospect of direct detection, [3] and indirect from the galactic center [4] have been recently published. It becomes interesting now, to see in which sense experimental limits on supersymmetric particles will be able to bring us information, or even to rule out some of these models, taking into account the complementarity between accelerator physics (LEP II, future LC) and astroparticle.

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_{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 [5]. 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[1]

$$M_a = \frac{g_a^2(\mu)}{2} \left\{ 2 \left[\frac{\delta_{\text{GS}}}{16\pi^2} + b_a \right] G_2(t, \bar{t}) F^T + \frac{2}{3} b_a \overline{M} \right\}, \quad (2.1)$$

$$A_{ijk} = -\frac{1}{3} \gamma_i \overline{M} - p \gamma_i G_2(t, \bar{t}) F^T + \text{cyclic}(ijk), \quad (2.2)$$

$$M_i^2 = (1-p) \gamma_i \frac{|M|^2}{9}. \quad (2.3)$$

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

$$M_{3/2} = -\frac{1}{3} \langle \overline{M} \rangle. \quad (2.4)$$

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 γ_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 δ_{GS} .

2.2. The dilaton dominated scenario

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

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

$$A_{ijk} = -\frac{k_s}{3} F^S - \frac{1}{3} \gamma_i \overline{M} + \tilde{\gamma}_i F^S \left\{ \ln(\mu_{\text{PV}}^2/\mu_R^2) - p \ln [(t + \bar{t})|\eta(t)|^4] \right\} + (ijk) \quad (2.6)$$

$$M_i^2 = \frac{|M|^2}{9} \left[1 + \gamma_i - \left(\sum_a \gamma_i^a - 2 \sum_{jk} \gamma_i^{jk} \right) \left(\ln(\mu_{\text{PV}}^2/\mu_R^2) - p \ln [(t + \bar{t})|\eta(t)|^4] \right) \right] + \left\{ \tilde{\gamma}_i \frac{M F^S}{6} + \text{h.c.} \right\}, \quad (2.7)$$

with

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

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 Kähler 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 (2.7) and (2.5), 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 $vev's$. 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 $M_{3/2}$).

3. ASTRO-PHENOMENOLOGICAL ASPECTS OF THE MODELS

In the specific context of the class of string models that we have considered, we have seen in [3] that the prediction regarding dark matter are strikingly different according to the type of supersymmetry breaking considered. In the case of moduli domination, one does not expect any signal in the forthcoming direct or indirect (neutrino) detection experiments. On the other hand, these experiments should not miss the neutralino signal in the case of dilaton domination. Thus, the detection of dark matter or the absence of detection may give key information on the nature of supersymmetry breaking, at least in the context of this given class of models.

We have also studied in [4] gamma-ray and synchrotron radiation emission from the Galactic center in this context. Typically, as it is the case for direct detection, models in the dilaton dominated SUSY breaking scenario lead to a higher annihilation rate than the moduli scenario. Concerning the continuum gamma-ray flux, both scenarios are within the reach of the experimental sensitivities of GLAST and HESS for a NFW halo profile. For the same profile, the gamma-ray line signal is suppressed and beyond the experimental sensitivity. The synchrotron emission is too low to be constrained by experiments even with a more cuspy profile.

Obviously, there are connections between these results and the detection of the LSP at colliders. Small direct detection cross sections or small indirect detection fluxes are obviously correlated with small production cross sections at colliders. In any case, it is interesting for collider searches to note the characteristics of the regions that satisfy the criterion of satisfactory relic density. For moduli domination, we have identified two regions of interest : one where $m_\chi \sim m_{\chi_1^+} \sim m_{\chi_2^0}$ through the bino and wino content of the LSP (for sufficiently large value of $\tan\beta$), and the other one close to the stau LSP region where $m_{\tilde{\tau}_1} \sim m_\chi$. In the case of dilaton domination, the cosmologically interesting region corresponds to a LSP with a proper higgsino content. Furthermore, the parameter space being closed (b_+ has a maximum value of ~ 0.57), this case gives an upper bound on neutralino mass of $m_\chi \lesssim 1500$ GeV.

We have sum up all these constraints and prospects using the complementarity between accelerator physics and astroparticle in the $(b_+, m_{3/2})$ plane in Fig. 1 for $\tan\beta = 35$. We clearly see that all the parameter space can be excluded if no discovery is made in the next generation of collider (Linear Collider of 1 TeV) or astroparticle experiments (indirect detection of neutrino from sun, ANTARES). This methodology can of course be applied in any class of string inspired model, especially the recently developed KKLТ set-up [7].

Acknowledgments

The author wish to thank all his collaborators for this work. He also wants to warmly thank P. Zerwas for sharing his incredible knowledge and enthusiasm, and the DESY theory group for their scientific and financial supports.

References

- [1] P. Binétruy, M. K. Gaillard and B. D. Nelson, “One loop soft supersymmetry breaking terms in superstring effective theories,” *Nucl. Phys. B* **604**, 32 (2001) [arXiv:hep-ph/0011081].
- [2] P. Binétruy, A. Birkedal Hansen, Y. Mambrini and B. D. Nelson, “Phenomenological aspects of heterotic effective models at one loop,” arXiv:hep-ph/0311291.
- [3] P. Binétruy, Y. Mambrini and E. Nezri, “Direct and indirect detection of dark matter in heterotic orbifold models,” *Astropart. Phys.* **22** (2004) 1 [arXiv:hep-ph/0312155].
- [4] G. Bertone, P. Binétruy, Y. Mambrini and E. Nezri, “Annihilation radiation of dark matter in heterotic orbifold models,” arXiv:hep-ph/0406083, accepted for publication in *Astropart. Phys.*
- [5] P. Binétruy, M. K. Gaillard and Y.-Y. Wu, *Nucl. Phys.* **B481** (1996) 109.
- [6] G.L. Kane, J. Lykken, S. Mrenna, B.D. Nelson, L.T. Wang, T.T. Wang *Phys.Rev.* **D67** (2003) 045008 arXiv:hep-ph/0209061.
- [7] A. Falkowski, O. Lebedev, Y. Mambrini, ‘SUSY Phenomenology of KKLТ Flux Compactifications’ to appear.

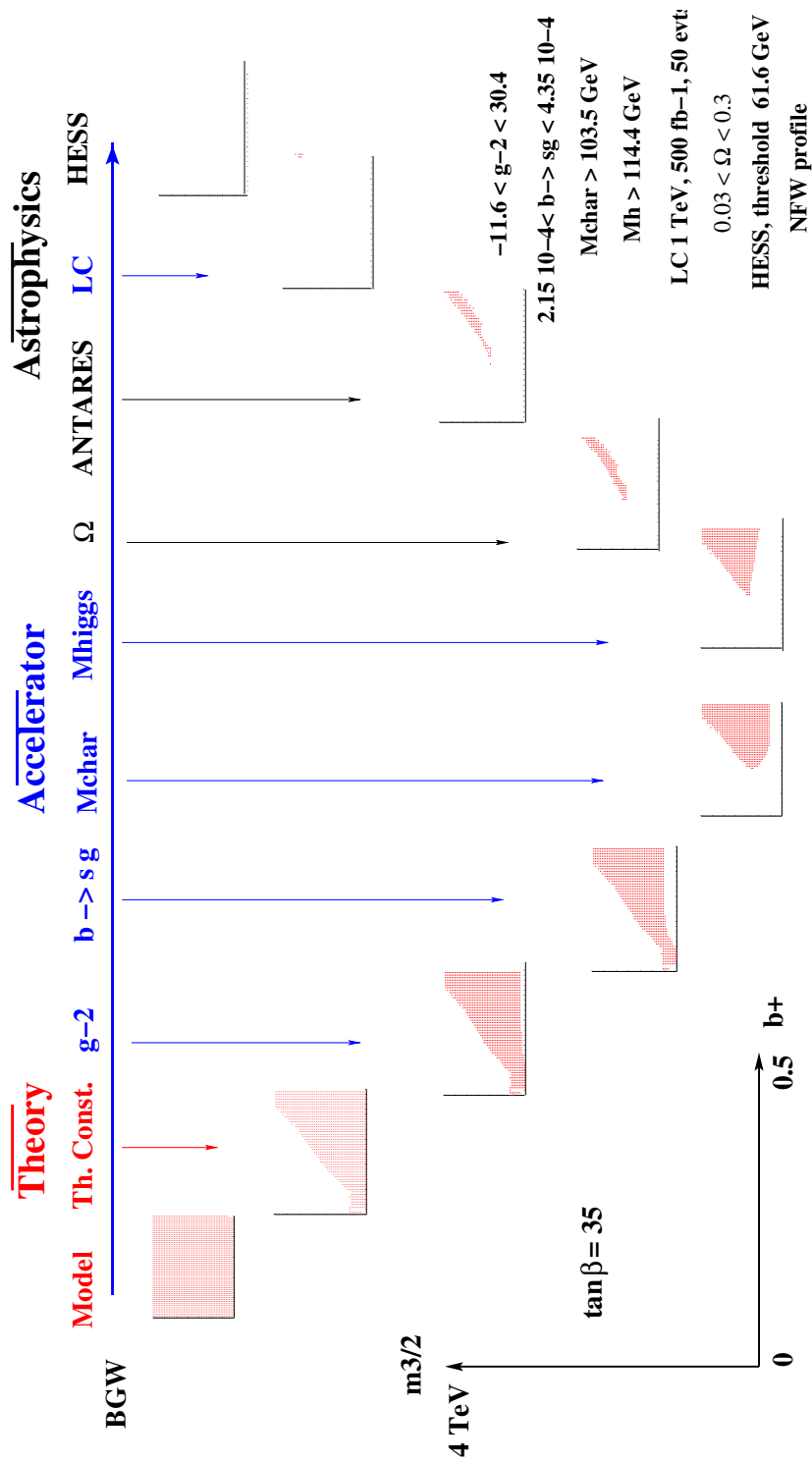


Figure 1: Example of restriction of the $(b_+, m_{3/2})$ parameter space in BGW model for $\tan\beta = 35$. We applied here the accelerator constraints coming from LEP II on chargino and higgs mass, on the $g-2$ and $b \rightarrow s\gamma$ rare processes, indirect detection from SUN by ANTARES, from the Galactic center from HESS and a future 1 TeV linear collider with a luminosity of 500 fb^{-1} and 50 events as a discovery in the chargino sector. All the points appearing in the $(b_+, m_{3/2})$ plane respect all the constraints for present experiment, and still survive if there is no observation from future experiment (LC, ANTARES, HESS).