RELIC ABUNDANCES AND DETECTION RATES OF NEUTRALINOS IN STRING-INSPIRED SUPERGRAVITY MODELS

B. de CARLOS
Centre for Theoretical Physics,
University of Sussex,
Falmer, Brighton BN1 9QH, UK

G.V. KRANIOTIS
Royal Holloway and Bedford New College,
University of London,
Egham, Surrey TW20 0EX, UK

We calculate relic abundances and detection rates of the neutralino (LSP) in string-inspired supergravity models with dilaton-moduli induced supersymmetry breaking. In particular we investigate universal scenarios for the soft-supersymmetry breaking terms from Calabi-Yau compactifications, as well as from the dilaton-dominated limit. Non-universal scenarios from orbifold string theory are also incorporated into the analysis. In all cases, in the cosmologically interesting region, we find $m_{LSP} \geq 50 \text{ GeV}$ and direct-detection rates in the range $O(10^{-3} \text{ events/(Kg day)})$–$O(10^{-4} \text{ events/(Kg day)})$. Indirect-detection rates from LSPs captured in the Sun are also calculated.

String theory is the leading candidate for the unification of the four fundamental interactions, gravitation plus gauge forces. Supersymmetry (SUSY), which is a hot experimental target of current accelerators and the future Large Hadron Collider (LHC), is naturally embedded in string theory. Besides solving in the technical sense the gauge hierarchy problem, SUSY provides us with a significant bonus: the LSP in string-inspired supergravity models with $R$-symmetry conservation is stable and it is an ideal candidate for dark matter. The detection of such a particle will constitute an overwhelming evidence for SUSY and non-baryonic dark matter. Since a lot of progress has been achieved in experiments designed to detect the LSP, and new strategies for ongoing and planned experiments have been decided, the study of relic abundances and

\(^a\)To appear in the Proceedings of the International Conference on the Identification of Dark Matter, IDM’96, Sheffield (UK), 8–12 September 1996.
detection rates of LSPs in string-inspired SUSY models is very well motivated and constitutes our contribution to this conference.

However, a satisfactory SUSY breaking mechanism in string theory is still lacking. As a result, a definite prediction for SUSY masses such as $m_{LSP}$ is not possible yet. The introduction of soft-susy breaking terms such as gaugino masses $M_a$, scalar masses $m_\alpha$, trilinear scalar soft terms $A_{\alpha\beta\gamma}$ and bilinear soft terms $B_\alpha$ in order to make SUSY theories realistic, discussed in this workshop by J. Ellis and A. Bottino\textsuperscript{1}, parametrizes our ignorance of the exact mechanism of SUSY breaking. Recently progress has been reported in deriving soft-terms from string theory\textsuperscript{2}. In this work the effect of SUSY-breaking is parametrized by the vacuum expectation values (vevs) of the $F$-terms associated to the dilaton ($S$) and the moduli ($T_m$) chiral superfields, generically present in large classes of four-dimensional supersymmetric heterotic strings. This attempt is an important step towards a theory of soft terms and for the extraction of model independent phenomenology from string theory. In this framework, the stringy soft-terms, in no-scale scenarios with zero cosmological constant depend on the gravitino mass $m_{3/2}$, and the Goldstino angle $\theta$ which specifies the extent to which the source of supersymmetry breaking resides in the dilaton versus moduli sector. This gives rise to various scenarios for the soft terms at the string scale $M_{str}$, among which we will consider here the following:\textsuperscript{b}

- In the large $T-$ limit of Calabi-Yau compactifications we have

  \[
  \begin{align*}
  m_\alpha^2 &= m_{3/2}^2 \sin^2 \theta \\
  M_a &= \sqrt{3} \frac{k_a \text{Re} S}{\text{Re} f_a} m_{3/2} \sin \theta \\
  A_{\alpha\beta\gamma} &= -\sqrt{3} m_{3/2} \sin \theta \\
  B_\mu &= m_{3/2} \left[ -1 - \sqrt{3} \sin \theta - \cos \theta \right] = A - m_{3/2} (1 + \cos \theta),
  \end{align*}
  \]

  where $k_a$ is the Kac–Moody level associated to the corresponding gauge group, and $f_a$ is the gauge kinetic function. Note that the soft terms are, in this case, universal (i.e. all scalar masses and all gaugino masses are the same at $M_{str}$).

- If the dilaton $F$-term dominates in the process of SUSY breaking, i.e. $\sin \theta = 1$, we get another universal scenario for the soft terms, the so-called Dilaton Dominated:

  \[
  \begin{align*}
  M_a &= M_{1/2} = -A, \\
  m_0 &= \frac{1}{\sqrt{3}} M_{1/2}
  \end{align*}
  \]
However also non-universal scenarios arise in some of the models. For instance in the O-I orbifold scenario the relevant soft-terms are given by

\[ m_\alpha^2 = m_{3/2}^2 (1 + n_\alpha \cos^2 \theta) \]
\[ A_{\alpha\beta\gamma} = -\sqrt{3} m_{3/2} \sin \theta - m_{3/2} \cos \theta (3 + n_\alpha + n_\beta + n_\gamma) \]
\[ M_a = \sqrt{3} m_{3/2} \frac{k_a \Re S}{\Re f_a} \sin \theta + m_{3/2} \cos \theta \frac{B'_a(T + T^*) \tilde{G}_2(T, T^*)}{32 \pi^3 \Re f_a} \]
\[ B_a = m_{3/2} [-1 - \sqrt{3} \sin \theta - \cos \theta (3 + n_H + n_{\tilde{H}})] \]  

where in Eq. (3) the quantities that parametrize the lack of universality for scalars, \( n_\alpha \), are the modular weights of the different fields (i.e. their charges under the \( T - duality \) string symmetry); their numerical values (which are usually negative integers) together with \( \Re T \) are chosen so that the interactions are unified at \( M_U \approx 2 \times 10^{16} \) GeV. All other quantities appearing in (3) can be found in [2].

Using the above scenarios Eqs. (1)-(3) for the soft terms as boundary conditions at \( M_{str} \), one can calculate the physical spectrum at the weak scale by solving the renormalization group equations for the masses of the different SUSY particles subject to combined constraints coming both from the experiment and from imposing a correct radiative electroweak symmetry breaking. The latter is enforced by minimizing the full one-loop effective potential. The LSP and dark matter candidate in these models neutralino (\( \chi^0_1 \)), which is a linear combination of the superpartners of the neutral electroweak gauge bosons and of the two neutral Higgs fields:

\[ \chi^0_1 = a_1 \tilde{B} + a_2 \tilde{W}^3 + a_3 \tilde{H}_1^0 + a_4 \tilde{H}_2^0 \]  

The relic abundance of the LSP, \( \Omega_{\chi} h^2 \), is proportional to the thermally averaged cross section \( <\sigma_{\text{ann}} v> \),

\[ \Omega_{\chi} h^2 \propto \frac{1}{<\sigma_{\text{ann}} v>} \]  

In the evaluation of \( <\sigma_{\text{ann}} v> \) we have considered the following set of final states: fermion-antifermion pairs, pairs of gauge bosons, Higgs-gauge boson pairs, pairs of Higgs bosons and also \( s \)-wave contributions for the two-gluon (\( gg \)) and (\( q\bar{q}g \)) final states in the spirit of [3]. We enforce the following

\[ \text{We thank M. Kamionkowski for providing us with the source code of Neutdriver.} \]
Figure 1: Plot of the relic abundance of the LSP (i.e. lightest neutralino) vs its mass (in GeV) for (a) large T–limit of Calabi-Yau compactifications (“x” corresponds to $\theta = \pi/4$, “∗” to $\theta = \pi/2$, “†” to $\theta = 3\pi/4$ and “✷” to $\theta = 7\pi/8$); (b) Dilaton Dominated models (where “∗” corresponds to $\tan \beta = 2.5$, “†” to $\tan \beta = 6$ and “✷” to $\tan \beta = 10$). The limits on $\Omega_\chi h^2$ are represented by the dashed lines.

Figure 2: Plots of the relic abundance of the LSP (i.e. lightest neutralino) (left) and the indirect detection rates of muon neutrinos emerging from the Sun (right) vs its mass (in GeV) for the O-I model (here “∗” corresponds to $\theta = \pi/2$, “†” to $\theta = 5\pi/8$ and “✷” to $\theta = 11\pi/16$). The limits on $\Omega_\chi h^2$ are represented by the dashed lines.
Figure 3: Plot of the direct detection rates of the LSP (i.e. lightest neutralino) vs its mass (in GeV) for (a) large T–limit of Calabi-Yau compactifications; (b) O-I model. The labels are the same as in Figs. 1,2.

constraints on the neutralino relic density

\[0.1 \leq \Omega_{\chi} h^2 \leq 0.3\] (6)

As we can see from Figs. 1 (universal models) and 2 (non-universal ones), the lower bound on \(\Omega_{\chi} h^2\) implies a lower limit on \(M_{\chi_0}\) of order 50 GeV. Further reductions on the phenomenologically viable parameter space can be obtained by imposing FCNC constraints on these spectra, such as that they give rise to a branching ratio for the process \(b \rightarrow s, \gamma\) within its experimental limits.

Let’s turn now to the detection rates of the LSP in these models. There are two ways to detect the neutralino: direct detection experiments try to observe a nucleus recoil after an LSP-nucleus scattering; in this case the detection rate is proportional to the local LSP density \(\rho_{\chi}\) as well as the elastic cross section \(\sigma_{\text{elastic}}\) of the LSP with a given nucleus. \(\sigma_{\text{elastic}}\) has two contributions: a coherent contribution, due to Higgs and squark \(\tilde{q}\) exchange diagrams, which depends on \(A^2\), \(A\) being the mass number of the nucleus; a spin-dependent contribution, arising from \(Z\) and \(\tilde{q}\) exchange again, proportional to the total angular momentum \(\lambda^2 J(J + 1)\). The differential detection rate is given by

\[\frac{dR}{dQ} = \frac{\sigma_{\text{elastic}} \rho_{\chi}}{4v_e m_{\text{LSP}} m_r^2} F^2(Q) [erf\left(\frac{v_{\text{min}} + v_e}{v_0}\right) - erf\left(\frac{v_{\text{min}} - v_e}{v_0}\right)]\] (7)

\(^d\)For a more detailed discussion about constraints on \(\Omega_{\chi} h^2\) see\(^5\).
where all the relevant quantities are defined in 4. In Fig. 3 we present results for the integrated rate $R$, i.e. the number of events per kilogram of $^{76}$Ge detector material per day. It can be seen that, in the cosmologically interesting region $(0.1 < \Omega_\chi h^2 < 0.3)$, the detection rates are in the range of $O(10^{-3} \text{ events/(Kg day)}) - O(10^{-4} \text{ events/(Kg day)})$. Note that the highest detection rates are obtained in the region of very small relic densities, i.e $\Omega_\chi h^2 \leq 0.05$.

Indirect detection experiments try to measure the flux of neutrino induced muons from captured LSPs in the Sun or Earth. In Fig. 2 we present results for muonic fluxes resulting from captured neutralinos in the Sun in the case of O-I model. In this case the resulting rates are far below the current experimental sensitivity.

Therefore we can conclude that by combining cosmological constraints on $\Omega_\chi h^2$ with correct radiative electroweak symmetry breaking and experimental limits on SUSY masses in string-inspired supergravity models, one obtains a strong lower limit on the neutralino mass i.e $M_\chi \geq 50\text{GeV}$.

Also given the optimism expressed by our experimental colleagues in this workshop that the desirable experimental sensitivity will be reached in shorter time we can say that WIMPs experiments will definitely help in testing the validity of the assumption of dilaton-moduli induced SUSY breaking in string theory.

Acknowledgments

We thank Ed Copeland for encouraging us to present our results at this workshop. GVK thanks the organizers for their warm hospitality and for creating such an enjoyable atmosphere. He also thanks C.E. Vayonakis for encouragement and many fruitful discussions. The work of BdeC was supported by a PPARC Postdoctoral Fellowship.

References

1. See J. Ellis, these same proceedings;
   See A. Bottino, these same proceedings.
2. A. Brignole, L.E. Ibáñez, C. Muñoz, Nucl. Phys. B 422, 126 (1994); erratum ibid., B 436 747 (1995).
3. C.-H. Chen, M. Drees, J.F. Gunion, hep-ph/9607421.
4. G. Jungman, M. Kamionkowski, K. Griest, Phys. Rep 267 195 (1996).
5. B. de Carlos, G.V. Kranidiotis, in preparation.
6. V. Berezinskii et al, Astropart. Phys. 5 1 (1995);
   V. Berezinskii et al, hep-ph/9603342.
7. F.M. Borzumati, M. Drees, M.M. Nojiri, *Phys. Rev.* D 51, 341 (1995); L. Bergström, P. Gondolo, hep-ph/9510252.
8. G.V. Kraniotis, *Z. Phys.* C 71, 163 (1996).
9. C.D. Buchanan *et al*, *Phys. Rev.* D 45, 4088 (1992).