Supersymmetry: The Final Countdown

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Abstract.
There is hope that the Large Hadron Collider (LHC) at CERN will tell us about the fate of supersymmetry at the TeV scale. Therefore we might try to identify our expectations for the discovery of SUSY, especially in the first years of operation of this machine. In this talk we shall concentrate on the simplest SUSY scheme: the MSSM with SUSY broken in a hidden sector mediated by interactions of gravitational strength (gravity-, modulus and mirage-mediation). Such a situation might be favoured in a large class of string inspired models. There is a good chance to identify such simple schemes by knowing the properties of the gaugino mass spectrum such as the gluino/neutralino mass ratios.

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INTRODUCTION

SUSY08 is the last conference of this series before the Large Hadron Collider (LHC) gets into operation. It might answer the question whether TeV-scale supersymmetry is a myth or reality [1]. We should therefore carefully analyze our expectations (and predictions) for supersymmetry in the (early) LHC area. As a guideline for the present talk we shall try to concentrate on the simplest models and schemes, identify clean signals and rely on theoretical (and personal) prejudices. We shall focus our attention on the minimal supersymmetric standard model (MSSM) and basic SUSY breakdown- and mediation-schemes like gravity, gauge and/or anomaly mediation. If we are lucky, LHC might become a gluino factory that allows us to extract useful information to disentangle various schemes via an analysis of the gaugino mass pattern.

THE MSSM

The MSSM is based on the gauge group \(SU(3) \times SU(2) \times U(1)\) with three families of quarks \((Q, \bar{U}, \bar{D})\) and leptons \((L, E)\), a pair of Higgs fields \((H, \bar{H})\) and a superpotential

\[
W = Q \bar{D} H + Q \bar{U} \bar{H} + L \bar{E} H + \mu H \bar{H}.
\]

The symmetries of the model would allow three more terms in the superpotential

\[
Q \bar{D} L + L \bar{E} L + U \bar{D} D
\]

which are problematic because of Baryon- and Lepton-number violation. As a low energy effective action the model might contain various soft SUSY breaking terms \([2]\): \(m_{1/2}\) for gaugino masses, \(m_0\) for scalar masses as well as trilinear (A) and bilinear (B) scalar couplings. The soft terms should be understood as the result of a spontaneous breakdown of SUSY at some higher energy scale. This simple scheme based on the MSSM makes two predictions and suffers from two problems. Attempts to construct a model with spontaneous SUSY-breakdown have to overcome four obstacles.

Two Predictions

The model predicts gauge coupling unification at a scale \(M_{\text{GUT}} \approx 10^{16}\text{GeV}\). The gauginos slow down the evolution of the gauge couplings towards higher energies and this fact leads to a GUT scale larger than in the non-supersymmetric case (avoiding some problems with proton decay via dimension-6-operators). The weak mixing angle is predicted to be \(\sin^2 \theta_W \approx 0.23\) for one pair of Higgs fields \((H, \bar{H})\).

The model predicts an upper bound on the mass of the lightest Higgs boson: at tree level \(m_h \leq m_Z\). The reason for this bound is the fact that the quadrilinear Higgs self-coupling is controlled by the gauge coupling. Radiative corrections (mainly because of the large top-quark Yukawa coupling) lead to an increase of the bound to \(m_h \sim 130\text{GeV}\). A larger mass for the lightest Higgs boson would rule out the MSSM.

Two Problems

Unlike the Standard Model the MSSM suffers from Baryon- and Lepton-number violation. In the MSSM, the
chiral multiplet for the lepton doublet (L) and the Higgs doublet (H) have the same quantum numbers and allow the problematic superpotential terms \((QLD, LLE, UDD)\) that among others would lead to rapid proton decay. The problem needs a (discrete) symmetry that forbids these terms. The simplest choice is so-called matter-number or R-parity \(R_p = (-1)^{3B+L+2S}\). Imposition of such a symmetry makes the lightest SUSY particle (LSP) stable and provides a convincing candidate for dark matter.

The second problem is connected to the mass term \(\mu H\bar{H}\) and is known as the \(\mu\)-problem. Such a term is allowed by supersymmetry and we have to ask the question why \(\mu\) is small compared to the GUT-scale. One might forbid \(\mu\) by a symmetry but at the end we need a nontrivial \(\mu\) of the order of the soft SUSY-breaking terms. This problem is a serious challenge to many attempts at realistic model building. Mechanisms to solve the \(\mu\) problem might be distinguished by either new terms in the superpotential or new terms in the Kähler potential.

### Four Obstacles

The soft SUSY-breaking terms of the MSSM should originate from a spontaneous breakdown of supersymmetry. First attempts at model building in the 1970’s and early 1980’s turned out to be more difficult than expected \([3, 4]\). There are some reasons for this.

1. **Sum Rule**

The supertrace of the (mass)\(^2\)-matrix vanishes at tree level for F-term SUSY breakdown \([5]\): this implies that we cannot push up all scalar masses in a uniform way. If some scales move up compared to the fermion mass, others have to become light. D-term breaking might give a positive contribution to \(\text{Str.} \mathcal{M}^2\), but gauge and/or gravitational anomalies spoil possible solutions. A suggested way out relies on the fact that the sum rule holds at tree level only. Thus we have to avoid mass-splittings at tree level (which have the wrong pattern) and rely on radiative corrections to lead to an acceptable result. The SUSY-breakdown sector couples only weakly to the observable sector and therefore has to be "remote" or "hidden".

2. **Gaugino Masses**

Gaugino masses vanish at the renormalizable (tree) level. A possible mass term \(F\chi\chi\) is a dim-5-operator and would require a coupling constant \(1/M\), where \(M\) denotes a new mass scale of the model. A resolution of the problem requires new physics at the mass scale \(M\) and/or radiative corrections. Again we need a new "remote" or "hidden" sector.

### 3. R-Axion

The MSSM with R-parity has a global (accidental) \(U(1)_R\)-symmetry for the renormalizable terms in the action. For R charge \(R(\theta) = 1\), we choose \(R(H,\bar{H}) = 1\) and \(R(Q, D, \bar{U}, L, \bar{E}) = 1/2\) and the allowed terms in the superpotential have R-charge 2. This R-symmetry forbids gaugino masses and has thus to be broken. If such a breakdown is spontaneous this would lead to a Goldstone boson. In the present case \(U(1)_R\) has a QCD anomaly and we obtain an axion. Such an axion does not exist. To avoid the problem we need an explicit breakdown of \(U(1)_R\). This again requires a new hidden sector, only weakly coupled to the MSSM.

### 4. Vacuum Energy

The vacuum energy of spontaneously broken global supersymmetry is strictly positive \(V = \Sigma F_i F_i^* + \frac{1}{2} D^2\). One might ignore this problem as it is only a problem in the presence of gravity. But it is good to see that in the framework of spontaneously broken supergravity we can have a vanishing (or small) cosmological constant.

This is all one has to know in order to construct a successful model of supersymmetry breakdown. One has to overcome the four obstacles mentioned and one has to worry about the \(\mu\)-term (and the value of the soft parameter \(B\)). Gaugino masses and the \(A\)-parameter need a breakdown of the (accidental) R-symmetry \(U(1)_R\). It is obvious from the discussion above that SUSY breakdown should happen in a hidden sector, that is only weakly coupled to the observable sector (MSSM). One also needs new physical phenomena that connect hidden and observable sector and mediate the breakdown of SUSY to the MSSM.

### SUSY BREAKDOWN AND MEDIATION

From obstacle 4 we know that in some way we should include gravitational interactions to cancel the vacuum energy. It would thus be a natural choice to have gravitational interactions to connect hidden and observable sector, a scheme called gravity mediation. The original suggestion \([6]\) relied on the mechanism of hidden sector gaugino condensation \(<\chi\chi> \sim \Lambda^3\), where \(\Lambda\) is the renormalization group invariant scale of the hidden sector confining gauge group. Supersymmetry is broken...
with an F-term: \( F \sim \Lambda^3/\text{M}_{\text{Planck}} \) leading to a gravitino mass
\[
m_{3/2} \sim \frac{\Lambda^3}{\text{M}_{\text{Planck}}} \tag{3}
\]
Observable sector gaugino masses are generated via the (nonrenormalizable) 4-fermion terms of supergravity
\[
\frac{1}{\text{M}^2_{\text{Planck}}} \tilde{g} \tilde{g} \chi \chi \tag{4}
\]
and we expect soft SUSY breaking terms of order \( m_{3/2} \) in the observable sector. All of the problems and obstacles are taken care of: soft scalar masses are generated via radiative corrections, \( m_{1/2} \) is generated via nonrenormalizable gravitational interactions that break \( U(1)_R \) explicitly to avoid the axion and the vacuum energy is tunable to the desired value. The \( \mu \)-term can be generated by higher order gravitational interactions.

This scheme was suggested before the full supergravity action coupled to matter was known. Subsequently, the supergravity action with more than one chiral multiplet has been worked out in full detail [7]. Surprisingly, it revealed a modification of the supertrace formula that allowed positive (mass)\(^2\) terms for all scalars. Properties of the models have been worked out in 1982 [8]. This lead to the first convincing implementation of SUSY breakdown in the MSSM and this scheme is since known as gravity mediation. Other attempts at SUSY breakdown were abandoned for almost a decade.

This scheme gained theoretical support in the framework of string theory. Especially the \( E_8 \times E_8 \) heterotic string seemed to be particularly suited for a hidden sector SUSY breakdown via gaugino condensation [9]. This was a new variant of gravity mediation in which certain moduli fields played the role of messengers between hidden and observable sector. This scheme of modulus and/or dilaton mediation is characterized via soft terms that are of order of magnitude of the gravitino mass. Details, of course, depend on the nature of the underlying string theory. In some cases, e.g. the heterotic theory with T-modulus mediation, soft terms were supressed at tree level. In this case the soft terms were generated through radiative corrections [10] and turned out to be smaller than the gravitino mass.

Gravity (or modulus) mediation is connected to physics at the Planck scale. Since gravity is a nonrenormalizable theory with many possible higher dimensional operators, one might be worried about the control of these operators and their contribution to the soft terms. Such a control, of course, has to come from a meaningful and consistent underlying theory such as string theory. Today one can often hear and read statements in the literature of the type: “gravity mediation has a flavour problem”, because of these nonrenormalizable operators that might induce flavor changing neutral current through the soft terms. Such statements are about as meaningful as statements like: “string theory has nothing to do with particle physics”. The question is not whether a given scheme can be inconsistent but rather the search for an underlying theory that avoids a given potential problem in a natural way. In fact, string theory offers many convincing ways to avoid the flavor problem of gravity mediation, e.g. via discrete family symmetries and/or universal mediation schemes such as dilaton domination in the heterotic theory.

In the early 1990’s other schemes called “gauge mediation” [11] were proposed (and revived) to solve the “flavour problem” of gravity mediation by construction. These schemes required a new hidden sector as well as new messengers at a mass scale smaller than \( M_{\text{GUT}} \) or \( \text{M}_{\text{Planck}} \). As a result these schemes had the universal property that \( m_{\text{soft}} \gg m_{3/2} \) and thus \( m_{3/2} \ll \text{TeV} \). The new sectors contain particles with standard model couplings and their presence might spoil gauge coupling unification (as predicted in the MSSM). Unification (if present) is no longer a prediction but the outcome of careful model building. The explicit construction of these models has to face the obstacles described earlier, such as the R-axion, the \( \mu \)-and the B-problem. It is not obvious till today how such a scheme can be realized in a simple and elegant form. It seems that the most convincing resolution of the problems requires higher order gravitational contributions [12, 13].

**LESSONS FROM LEP**

Today we hope that the LHC will clarify the situation with supersymmetry at the TeV-scale. We should remember, however, that similar expectations existed before the start of the LEP machine in 1989. The first stage of LEP did not see SUSY particles but gave the encouraging sign of gauge coupling unification with the resurrection of (supersymmetric) grand unified theories. Discovery was expected at the second stage: LEPII. What we got was a support for grand unification and a lower bound on the Higgs boson mass \( m_h > 114 \text{ GeV} \). Electroweak precision data is consistent with the standard model, prefers a rather low Higgs mass and gives a good fit to the MSSM (in contrast to other alternatives of physics beyond the standard model). So we have no direct sign for SUSY, but some encouragement. Still, a large part of the parameter space is gone. So, what keeps us going? Certainly, gauge coupling unification of the MSSM is encouraging, so is the perfect agreement with electroweak precision data. The model has a convincing dark matter candidate through the LSP-neutralino. The value of \( \langle g - 2 \rangle \) of the muon seems to be at odds with the standard model and could easily be a first indirect sign of
SUSY. But we do not know and we need the LHC to judge. But what should we expect. After more than 20 years of model building we have many, many models as well as a plethora of mediation schemes. SUSY could manifest itself in various different ways and we have to wait for the LHC to provide the answer.

THEORETICAL GUIDE LINES

Still we hope that nature is kind to us and chooses a simple and compelling scheme. We thus stick to the MSSM with its properties of unified coupling constants. Theoretical input will come from grand unification and string theory. We want to get an idea what we can learn from strings for particle physics. Recent progress has come from

- explicit model building towards the MSSM and the framework of the heterotic braneworld and the concept of local grand unification [14]
- moduli stabilization and SUSY breakdown [15, 16, 17, 18] and its consequences for mediation schemes.

The importance of the mechanism of the fine tuning of the vacuum energy for the soft SUSY breaking terms has only been appreciated recently [19, 20] and is closely connected to a scheme now known as mirage mediation [21]. In its simplest form it has been found in the framework of type IIB string theory in the presence of background 3-form fluxes and gaugino condensates, completed with an uplifting sector that adjusts the cosmological constant to the desired value [22]. In such a set-up, the superpotential contains contributions from fluxes and gaugino condensates

$$W = \text{flux} - \exp(-X)$$

where “flux” is a small quantity in terms of the Planck mass and thus X (related to the vev of a modulus) is a moderately large number. In fact one obtains

$$X \sim \log(M_{\text{planck}}/m_{3/2})$$

providing a “little hierarchy”, resulting from the the appearance of the logarithm of the Planck-weak scale hierarchy. The tree level contribution from modulus mediation is therefore suppressed by the factor

$$\log(M_{\text{planck}}/m_{3/2}) \approx 4\pi^2$$

and radiative contributions from SUSY breakdown in the uplifting sector become competitive and lead to a mixed mediation scheme. A simple scheme of mediation via radiative corrections is known under the name of anomaly mediation [23], where the individual soft terms are controlled by the $\beta$- and $\gamma$- functions of the MSSM. As we will explain in a moment, a mixed anomaly-modulus mediation scheme leads the phenomenon of mirage mediation [20, 24, 25].

Mirage Mediation

In such a scheme we have mass relations reflecting the little hierarchy

$$m_X \sim \langle X \rangle m_{3/2} \sim \langle X \rangle^2 m_{\text{soft}},$$

i.e. gravitino and moduli are heavy, and we obtain a characteristic pattern of soft breaking terms. To see this let us consider the gaugino masses

$$M_{1/2} = M_{\text{modulus}} + M_{\text{anomaly}}$$

as a sum of two contributions of comparable size. $M_{\text{anomaly}}$ is non-universal below the GUT-scale and proportional to the $\beta$-function, i.e. negative for the gluino and positive for wino and bino.

With the evolution of gauge coupling constants as displayed in Fig. 1, we obtain the evolution of the gaugino masses (Fig. 2) exhibiting a mirage unification at an intermediate scale.

The splitting of the values at the GUT scale is compensated by the evolution (proportional to the same $\beta$-function) and the gaugino masses meet at the mirage scale

$$\mu_{\text{mirage}} \approx M_{\text{GUT}} \exp(-8\pi^2/\rho),$$

where $\rho$ denotes the ratio of modulus versus anomaly mediation. Thus

$$M_a = M_a(\rho + b_a g_a^2) = \frac{m_{3/2}}{16\pi^2}(\rho + b_a g_a^2),$$

where $\rho \to 0$ would correspond to pure anomaly mediation. The outcome is a very predictive scheme where
FIGURE 2. Mirage unification of gaugino masses at an intermediate scale.

all the soft terms are determined by just two parameters: \( m_{3/2} \) and \( \rho \). There are constraints on the parameters as can be seen in Fig. 3. For small \( \rho \) one typically has problems with the presence of tachyons. Even if one removes these tachyons one has to face problems with either inconsistent candidates for the (stable) lightest supersymmetric particle (LSP), the existence of colour- and charge-breaking vacua and/or the absence of electroweak symmetry breakthrough. There is also a lower limit on the gravitino mass from the Higgs mass bound from LEP. But suprisingly, for such a simple scheme with just two free parameters, a large part of the parameter space is consistent with all presently know constraints \([26]\).

The “MSSM Hierarchy Problem”

The simplest scheme predicts a rather high scale for the mass of the gravitino and LSP-neutralino. One might thus be worried about the necessity of a (mild) fine tuning to obtain a rather low mass for the electroweak gauge bosons less than a hundred GeV, a fact that has been called the “MSSM hierarchy problem” or the “little hierarchy problem”. Electroweak symmetry breakdown requires the relation

\[
\frac{m_Z^2}{2} = -\mu^2 + \frac{m_{\tilde{H}_1}^2 - m_{\tilde{H}_2}^2}{\tan^2 \beta - 1}
\]

(12)

and there are large corrections to \( m_{\tilde{H}}^2 \). The influence of the various soft terms is given by

\[
m_Z^2 \simeq -1.8 \mu^2 + 5.9 M_2^2 - 0.4 M_2^2 - 1.2 m_{H_u}^2 +
\]

\[
+0.7 m_{\tilde{H}_1}^2 - 0.6 A_t M_3 + 0.4 M_2 M_3 + \ldots
\]

(13)

We see that the gluino mass is the driving force for this evolution. Mirage mediation improves the situation especially for small \( \rho \), because of a reduced gluino mass and a “compressed” spectrum of the supersymmetric partners. Explicit model building (based on the mirage scheme) towards a solution of this problem can be found in ref.\([27]\).

Explicit Schemes

The different schemes differ by the mechanism responsible for the fine tuning of the vacuum energy, sometimes called the “uplifting sector”.

Uplifting by anti-D3 branes

This is the original suggestion by KKLT \([22]\) for uplifting the vacuum energy in Type IIB string theory with matter on D7-branes. The scheme leads to \( \rho \sim 5.5 \) and a mirage scale as displayed in Fig. 2. Observe that this value of \( \rho \) is consistent with the constraints of Fig. 3. It should be stressed that this scheme leads to what one might call pure mirage mediation: gaugino masses and scalar masses all meet at a common mirage scale.

Uplifting via matter superpotentials

Here the uplifting comes from the F-term contribution of a hidden sector of “matter” fields in a hidden sector that breaks supersymmetry \([28]\). It has more free parameters and allows a continuous variation of \( \rho \). It also leads to potentially new contributions for the A-parameters and soft scalar mass terms. Gaugino masses still meet at the mirage scale, but the soft scalar masses might be dominated by the modulus F-terms and do not show the same mirage pattern. The constraints on \( m_{3/2} \) and \( \rho \) are rather similar to the case of pure mirage mediation as displayed in Fig. 4.
FIGURE 4. Constraints on $\rho$ in a scheme of relaxed mirage mediation, as found in the heterotic theory with F-term uplifting, where the dilaton is the relevant modulus for SUSY breakdown [29].

Again there appears a lower limit on $\rho$ from the requirement of electroweak symmetry breakdown and the absence of problematic LSP as well as a lower limit on $m_{3/2}$ from the LEP data. The region to the right hand side is allowed and the dark (brown) strip indicates the region where the abundance of the LSP-neutralino gives the right amount of dark matter.

**General F-term uplifting**

This “relaxed” mirage mediation scheme, where only the gaugino masses show a mirage pattern is rather common for F-term uplifting [30]. Still, the “pure” mirage pattern is possible as well, but only for certain values of the parameters. In general, the patterns for the soft scalar mass terms and the values of the A-parameters are strongly model dependent.

The main message from here is that gaugino mass predictions are more robust than predictions for the other soft parameters and that in the given situation the mirage pattern is rather generic.

**D-term uplifting**

Uplifting via D-terms alone seems rather problematic. In supergravity there is the relation

$$D = \frac{F}{W}$$

which vanishes in the KKLT [22] minimum with $F = 0$ and $W \neq 0$. Such a minimum can therefore not be uplifted by D-terms alone [20].

In additions we know that generically

$$F \sim m_{3/2}M_{\text{Planck}} \quad \text{while} \quad D \sim m_{3/2}^2$$

such that for $m_{3/2} \ll M_{\text{Planck}}$ the D-terms are irrelevant [31].

**THE GAUGINO CODE**

So, what should we expect to see in the early stage of the LHC where we scatter protons on protons, i.e. quarks/gluons on quarks/gluons. Therefore LHC is a machine designed to produce strongly interacting particles. If supersymmetry is the physics beyond the standard model this will lead to a production of squarks and gluinos. If we are lucky and the mass of the gluino will not be too large, LHC might become a gluino factory. The produced gluino will decay in a cascade down to standard model particles and the LSP that might escape undetected, but leaving a trace of “missing energy”. A first step to test these ideas at the LHC would be the study of the pattern of gaugino masses [32]. This is particularly interesting as the values for the gaugino masses show a rather mild model dependence.

To be specific, let us assume models with the particle content of the MSSM and the measured values of the gauge coupling constants at the TeV scale. They are
approximately given by
\[ g_1^2 : g_2^2 : g_3^2 \simeq 1 : 2 : 6. \]  
(16)

The evolution of the couplings would then lead to unification at a scale around \(10^{16}\) GeV (as shown in Fig. 1).

Observe now that the evolution of the gaugino masses is closely related to the evolution of the gauge couplings. For the MSSM the ratio \(M_a/g_2^a\) does not run at one loop. This provides rather robust statements about the gaugino masses and gives us the hope that gaugino mass relations might be the key to reveal properties of the underlying scheme of supersymmetry breakdown. We can identify three basic patterns of gaugino masses.

### SUGRA Pattern

In simple schemes like gravity and modulus mediation with universal soft terms at the GUT scale this pattern would be
\[ M_1 : M_2 : M_3 \simeq 1 : 2 : 6 \simeq g_1^2 : g_2^2 : g_3^2. \]  
(17)

The LSP neutralino \(\chi_1^0\) will be predominatly a Bino and
\[ G = \frac{M_3}{m_{\chi_1^0}} \simeq 6, \]  
(18)
a characteristic signature for these schemes.

### Anomaly Pattern

Just below the GUT scale the gaugino mass ratios are given by the MSSM \(\beta\) functions
\[ \beta_1 : \beta_2 : \beta_3 = 33 : 5 : (-15) \]  
(19)
leading to a mass pattern at the TeV scale
\[ M_1 : M_2 : M_3 \simeq 3.3 : 1 : 9 \]  
(20)
as the signal of anomaly mediation.

The LSP neutralino is predominantly Wino and we obtain
\[ G = \frac{M_3}{m_{\chi_1^0}} \simeq 9, \]  
(21)
a rather high value.

Of course, pure anomaly mediation is problematic because of tachyonic sleptons. Still, the problems with these tachyons could be removed by contributions to the soft scalar mass terms without changing the gaugino mass pattern. Therefore one should keep this simple pattern in mind.

### Mirage Pattern

The mirage pattern seems to be rather generic for the schemes discussed in the previous section. We have mixed boundary conditions at the GUT scale and the pattern depends on the parameter \(\rho\). For \(\rho \sim 5.5\) we obtain
\[ M_1 : M_2 : M_3 \simeq 1 : 1.3 : 2.5 \]  
(22)
while for (the potentially problematic) limiting case \(\rho \sim 2\) one gets
\[ M_1 : M_2 : M_3 \simeq 1 : 1 : 1. \]  
(23)

The LSP is predominantly bino and we have a “compressed” spectrum of gaugino masses with a smaller value of
\[ G = \frac{M_3}{m_{\chi_1^0}} < 6. \]  
(24)

With some precision in the determination of the gaugino masses we might be able to test gaugino mass sum rules. As an example note that the combination
\[ r = \frac{1}{M_3} (2(M_1 + M_2) - M_3) \]  
(25)
will approximately vanish both in the SUGRA and anomaly pattern. In this context a nonvanishing \(r\) would then be a signal for the mirage scheme and allow a determination of \(\rho\).

### Uncertainties

These simple schemes have quite some predictive power since the results are given in terms of MSSM parameters, i.e. gauge coupling constants and the \(\beta,\gamma\)-functions. If we are lucky such a situation is realized in nature and we might learn a lot just from a study of the gaugino mass patterns. Of course, there could be uncertainties [33] that cannot be controlled through the parameters of the MSSM. These include threshold corrections at intermediate scales that are characteristic for gauge mediation. In string theories we might have threshold corrections at the GUT scale with (in principle) unpredictable consequences for the low energy spectrum. Further uncertainties might arise from contributions that depend on the Kählerpotential of hidden/observable sector fields [32].

### Stringy Expectations

As we have seen, the mirage pattern has been discovered in the framework of TypeIIB string theory with matter on D7 branes [20]. In the same theory for matter on
D3 branes one would expect the anomaly pattern for the gaugino masses. Of course, here we have to worry about the presence of tachyonic sleptons, but the spectrum of the scalars is strongly model dependent and one might remove the tachyons without disturbing the gaugino mass ratios. In the heterotic theory we face a similar situation. In the case where the dilaton is the relevant modulus for SUSY breakdown one would expect a variant of mirage mediation [29]. If instead, other moduli than the dilaton are responsible for SUSY breakdown, the anomaly contribution might be relevant, probably spoiled by string theory threshold contributions at the large scale [14]. In the recently discussed M-theory models compactified on manifolds with $G_2$ holonomy [34], the basic scheme is mirage mediation with potential large contributions from the Kähler-potential terms [32] mentioned previously.

OUTLOOK

It is up to the LHC now to tell us the truth. We might be confident that the phenomenon of gauge coupling unification will survive the LHC era. It might also give us the hint how nature solves the hierarchy problem (if it really cares about it). Supersymmetry is still one of the favoured schemes for the physics at the TeV scale. If it exists we shall have much fun to figure out the spectrum [35] and try to select the underlying models. This might take some time. But, if we are lucky nature might have chosen a simple scheme and even at the early stages of the LHC we might be able to test these ideas. Certainly the pattern of the gaugino masses will be a crucial key in this enterprise.

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