CONSEQUENCES OF LOW ENERGY
DYNAMICAL SUPERSYMMETRY BREAKING

ANN E. NELSON
Department of Physics Box 351560
University of Washington, Seattle, WA 98195-1560

ABSTRACT
Relatively simple models can be constructed in which supersymmetry is dynamically broken at energies of $10^5 - 10^7$ GeV. Models of this kind do not suffer from the naturalness and cosmological difficulties of conventional supergravity models, and make definite predictions for the spectrum of supersymmetric particle masses. Thus “Renormalizable Visible Sector Models” are a viable alternative to more conventional approaches. This talk mostly summarizes the results of reference 1.

1. Introduction

A supersymmetric extension of the Standard Model, with supersymmetry dynamically broken by exponentially small nonperturbative effects, provides an attractive technicolor-like solution to the hierarchy problem, while allowing the quarks and leptons to get mass from Yukawa couplings. Usually we assume that supersymmetry is spontaneously broken in a gravitationally coupled “hidden” sector leading to soft explicit supersymmetry breaking terms in the effective theory. The resulting model, known as the Minimal Supersymmetric Standard Model (MSSM) is superficially simple and appealing, but has several theoretically unpleasant features.

1. The Desert. A fun aspect of supersymmetry is that it allows us to obtain exact results about strongly interacting gauge theories. However in the MSSM we have nothing but boring perturbative physics to explore below the Planck scale and the interesting dynamics of supersymmetry breaking is hidden.

2. The Proliferation of Parameters. If nonrenormalizable interactions induced by Planck scale physics have the most general allowed form there are over 100 new parameters required by soft supersymmetry breaking terms.

3. Naturalness. The Standard Model explains the observed absence of baryon and lepton number nonconservation, and the small size of weak CP violation and Flavor Changing Neutral Currents (FCNC) in a satisfying way, without resorting to speculation about Planck scale physics. In the MSSM the low energy effective theory provides no compelling reason for new sources of violation of these quantum numbers to be absent.

4. The Scale of Supersymmetry Breaking. In the MSSM the superpartner masses are theoretically not very constrained, and some sort of conspiracy
seems to be required to keep them all out of current experimental reach.

5. The Mechanism for Dynamical Supersymmetry Breaking (DSB). In the MSSM is the supersymmetry breaking sector is hidden, thus one doesn’t have to specify it and one can imagine that it is beautiful. However explicit hidden sector models are uncompelling.

6. Cosmology. Most existing hidden sector models of supersymmetry breaking produce a weak scale gravitino and weak scale scalars with gravitational strength couplings. These typically dominate the energy density of the universe until temperatures below 1 keV, which is later than required by nucleosynthesis.

An alternative to the MSSM, which ameliorates all of these problems, is to communicate supersymmetry breaking to the superpartners via renormalizable gauge interactions. Then the squark, slepton and gaugino masses are calculable from a small number of parameters and the flavor symmetries of gauge interactions automatically guarantee that the squarks and sleptons are sufficiently degenerate to prevent FCNC. The trouble-free cosmology of such models was discussed in ref. 2.

2. The Minimal Model of Dynamical Supersymmetry Breaking

The simplest known model in which it is possible to obtain DSB in a limit where a reliable calculation can be made has gauge group SU(3)×SU(2) (“supercolor”) and matter fields in the (3,2) + 3(3,1) + (1,2) representation (“supercolored fields”) and the most general renormalizable superpotential allowed by the gauge symmetry. One might think that the simplest possible theory would involve this model together with gravitational transmission of the information that supersymmetry is broken to ordinary matter, however such models have difficulty obtaining sufficient ordinary gaugino masses. The simplest way to transmit the information that supersymmetry is broken is to gauge an additional U(1) (“messenger hypercharge”) which is carried by the supercolored fields and also by some additional supercolor singlet “messenger fields”. Thus we believe that the simplest possible theory of supersymmetry breaking involves an additional SU(3)×SU(2)×U(1) gauge group. Some of the messenger fields couple to a gauge singlet field “S”, which gets an expectation value and whose F-term becomes nonzero at two loops. S also couples to new quark and lepton superfields with vector-like quantum numbers under the ordinary SU(3)×SU(2)×U(1).

3. Consequences

Now we can have some fun and calculate the spectrum of ordinary superpartner masses induced by ordinary gauge interactions with the new vector-like particles. We find that the superpartner masses satisfy to leading order in $F_S$ and gauge interactions

$$m_{\text{gaugino}} = k_F l^{(a)} \frac{g_s^2}{16\pi^2} \frac{F_S}{S}$$

$$m_{\text{squark, slepton}}^2 = \sum_a C_F l^{(a)} \left( \frac{g_s^2(a)}{16\pi^2} \right)^2 \frac{F_S^2}{S^2} ,$$
where $a$ denotes the gauge group, $k_F$ is the index of the vector-like representation and $C_F$ is the Casimir. Note that these predictions do not depend on the specific supersymmetry breaking sector but are typical of models where gauge interactions communicate supersymmetry breaking. Other effective supersymmetry breaking terms, such as trilinear scalar interactions as well as other terms which are not soft, can also be computed and are small. To this order the Higgs mass squared also comes out positive (and degenerate with the left handed sleptons), however at three loops there is the usual large negative contribution induced by the top quark radiative correction\textsuperscript{4}.

Another model independent prediction of low energy supersymmetry breaking is that the gravitino is light and is the Lightest Supersymmetric Particle (LSP), with mass $m_{3/2} = M_s^2/m_p$, where $M_s$ is the supersymmetry breaking scale. Gravitino cosmology constrains $m_{3/2}$ to be less than 10 keV, to avoid contributing too much mass density to the universe\textsuperscript{5}, giving an upper bound on $M_s$ of $10^7$ GeV. A lower bound on $M_s$ can be obtained by noting that DSB models generically contain a spontaneously broken U(1)$_R$ symmetry and a Goldstone boson known as the R-axion\textsuperscript{6}. The simplest way to give the R-axion an acceptably large mass\textsuperscript{6,7} is to explicitly break the symmetry via dimension-5 operators suppressed by $1/m_p$—the mass will be greater than 10 MeV for $M_s > 10^5$ GeV. The Bino is typically the next to lightest supersymmetric particle (NLSP), and will decay into a gravitino and a photon or $Z$, with lifetime\textsuperscript{8}

$$\tau_{\text{Bino}} \sim 8\pi \frac{M_s^4}{M_{\text{Bino}}^5}.$$ 

If supersymmetry is discovered, a search for the decay of the NLSP will provide a lower bound on the supersymmetry breaking scale, or evidence for low energy supersymmetry breaking.

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5. References