

Naturalized and simplified gauge mediation

Ofer Aharony^{ab} and Nathan Seiberg^a

^a*School of Natural Sciences, Institute for Advanced Study
Einstein Drive, Princeton, NJ 08540, U.S.A.*

^b*Department of Particle Physics, Weizmann Institute of Science
Rehovot 76100, Israel*

E-mail: Ofer.Aharony@weizmann.ac.il, seiberg@ias.edu

ABSTRACT: Following recent developments in model building we construct a simple, natural and controllable model of gauge-mediated supersymmetry breaking.

KEYWORDS: Supersymmetry Phenomenology, Supersymmetry Breaking, Supersymmetric Effective Theories.

JHEP02(2007)054

It is an important challenge to find an explicit model of dynamical supersymmetry breaking [1] which satisfies all known experimental constraints. The most promising avenue is that of gauge-mediated supersymmetry breaking [2–10] (for a review, see e.g. [11]).

Unfortunately, all these models are extremely complicated. The complexity originates from the sector of the theory which dynamically breaks supersymmetry and is made worse by the messengers.

Following [12], many authors have recently found extremely simple models of supersymmetry breaking in a metastable state [12–23] (for earlier work see e.g. [8–10],[24–27]). One can hope to use the large global symmetry of these simple models to construct a model of direct gauge mediation in which no messengers are needed [28], as was recently discussed in [12, 16, 21, 23]. Here, following [22], we will explore a gauge mediation model with messengers.

The main point of this paper is to make the model of [22] completely natural. That model has a number of mass scales which were put in “by hand.” In a completely natural model such scales should arise dynamically. This is easily achieved, as in [19, 20], by introducing another gauge group and replacing every dimensionful constant by the gluino bilinear of that group divided by an appropriate power of a high scale, which we will take to be the Planck scale M_p .

Our model is extremely simple and completely natural. It also has many simple variants. We do not necessarily advocate this model as a model of Nature, but merely as an illustration that the traditional ideas of naturalness and dynamical supersymmetry breaking can be realized in a simple and economical model.

Our model includes three sectors:

- i) The first sector is a supersymmetric Yang-Mills theory with some non-Abelian gauge group G with no charged fields. It is characterized by a scale $\tilde{\Lambda}$ where it becomes strong. The purpose of this sector is to dynamically generate the mass parameters in the Lagrangian of [22], as in [19, 20]. The scale $\tilde{\Lambda}$ is larger than any other scale in the problem except M_p , and therefore the dynamics of this sector should be analyzed first.
- ii) The second sector breaks supersymmetry. Here we follow [12] and consider the supersymmetric QCD (SQCD) theory with gauge group $SU(N_c)$ and with N_f quarks Q_i, \tilde{Q}^j , with $N_c + 1 \leq N_f < 3N_c/2$, characterized by a scale Λ . Clearly, this theory can be replaced by other theories which similarly break supersymmetry. We do not include mass terms for the quarks in this sector. These arise only through the coupling to the first sector via high dimension operators.
- iii) The third sector includes the MSSM (or some other supersymmetric generalization of the standard model), coupled to messenger fields f and \tilde{f} (which can be, for instance, in the $\mathbf{5}$ and $\overline{\mathbf{5}}$ of an $SU(5)$ GUT group). We do not include explicit mass terms for the messengers.¹ Such a mass term arises from the coupling to the first sector via high dimension operators.

¹With the exception of the μ parameter which we do not discuss, the gauge symmetries forbid mass terms for the MSSM fields.

Suppressing factors of order one, the terms in the action which are relevant for our analysis are of the form

$$\int d^2\theta \left[\frac{1}{M_p} Q_i \tilde{Q}^i f \tilde{f} + \text{Tr}(W_\alpha^2) \left(\frac{1}{g_{\text{SYM}}^2} + \frac{1}{M_p^2} (Q_i \tilde{Q}^i + f \tilde{f}) \right) \right], \quad (1)$$

where W_α is the chiral multiplet including the gauge field of the group G . Here we assumed that the MSSM fields do not couple to Q and W_α at the leading order.² In addition to (1) there are standard terms for the MSSM fields, and for the SQCD sector which breaks supersymmetry, and canonical Kähler terms. For simplicity we assumed that the action preserves an $SU(N_f)$ flavor symmetry of the SQCD quarks. This assumption is not essential, and our conclusions do not change if arbitrary $SU(N_f)$ -breaking couplings are allowed in (1).

We take

$$\Lambda \ll \tilde{\Lambda} \ll M_p. \quad (2)$$

The Planck scale M_p may be replaced by any other high-energy scale which we do not discuss in detail. Note that the superpotential (1) does not have a continuous R-symmetry (but just an R-parity symmetry).

The largest scale in the model is $\tilde{\Lambda}$. Here, the gauge theory of G becomes strong. Gaugino condensation in this theory leads to $\langle \text{Tr}(W_\alpha^2) \rangle \sim \tilde{\Lambda}^3$, generating masses for the SQCD quarks Q and the messengers f

$$m_Q \sim m_f \sim \frac{\tilde{\Lambda}^3}{M_p^2}. \quad (3)$$

The next scale we encounter is the scale Λ where the SQCD theory becomes strongly coupled. We will take

$$m_Q \ll \Lambda. \quad (4)$$

Then, below the scale Λ the weakly coupled degrees of freedom are those of the dual “magnetic” theory [29]. In terms of these degrees of freedom we have

$$W = \Phi_i^j q^i \tilde{q}_j + m_Q \Lambda \text{Tr}(\Phi) + (m_f + \frac{\Lambda}{M_p} \text{Tr}(\Phi)) f \tilde{f}, \quad (5)$$

where q and \tilde{q} are the dual quarks (or the baryons if $N_f = N_c + 1$ [30]) and $\Phi_i^j \equiv Q_i \tilde{Q}^j / \Lambda$. As discussed in [12], when $m_Q \ll \Lambda$ this theory has a metastable SUSY-breaking vacuum, in which the F -term of Φ is of order $F_\Phi \sim m_Q \Lambda$.

The low energy spectrum in this vacuum has a number of massless fields including Goldstone bosons of some global symmetries and some of the fermionic components of Φ [12]. These can be made massive by gauging the global symmetry, by including $SU(N_f)$ -violating couplings in (1), or by including other higher dimension operators [22].

²This can be made natural with an appropriate symmetry. Without such a symmetry this is automatic for one of the couplings in (1) (this is the definition of the messenger fields), but we assume that it is true for both.

In this supersymmetry breaking vacuum, the effective superpotential for the messenger fields well below the scale Λ takes the form

$$W = S f \tilde{f}, \tag{6}$$

which is the standard form of gauge-mediated theories of supersymmetry breaking, with

$$\langle S \rangle \equiv s + \theta^2 F_s = m_f + \theta^2 \frac{\Lambda}{M_p} F_\Phi \simeq \frac{\tilde{\Lambda}^3}{M_p^2} + \theta^2 \frac{\Lambda^2 \tilde{\Lambda}^3}{M_p^3}. \tag{7}$$

It is easy to check that all other possible terms which we did not write down explicitly in (1) merely give small corrections to (7) and do not destabilize the SUSY-breaking vacuum (though they could shift it by a small amount).

Note that in addition to the SUSY breaking vacuum analyzed above, this model also has several SUSY-preserving vacua, as expected from a theory with no R-symmetry [31]. These vacua include the SUSY-preserving vacua of the SQCD theory, and they are all far away from the SUSY-breaking vacuum for the parameters we choose, such that the lifetime of this vacuum is very long.

As discussed, for instance, in [22], in order for the analysis above to be valid and in order to find a realistic spectrum several inequalities need to be satisfied. For the longevity of the metastable vacuum in the SQCD sector we need

$$\epsilon = \frac{m_Q}{\Lambda} \simeq \frac{\tilde{\Lambda}^3}{\Lambda M_p^2} \ll 1. \tag{8}$$

In order for the messenger fields f not to be tachyonic we require $F_s \lesssim |m_f|^2$, or

$$\Lambda^2 M_p \lesssim \tilde{\Lambda}^3. \tag{9}$$

Finally, in order to preserve the successes of gauge mediation, including the lack of flavor changing neutral currents, we would like the gauge-mediated contribution to the scalar masses to be much larger than other contributions which arise from terms of the form $\frac{1}{M_p^2} Q^\dagger Q v^\dagger v$ in the Kähler potential (v is a typical MSSM chiral superfield). This leads to a bound like

$$m_{\text{SUSY}} \sim \frac{\alpha_{\text{MSSM}}}{4\pi m_f} F_s \gtrsim 100 \cdot \frac{1}{M_p} F_\Phi \tag{10}$$

and hence

$$\frac{\tilde{\Lambda}^3}{\Lambda M_p^2} \lesssim 10^{-4}, \tag{11}$$

which is a stronger version of (8).

Expressed in terms of the typical scale expected for SUSY breaking and the Planck scale

$$\mu \sim \frac{F_s}{m_f} \sim \frac{\Lambda^2}{M_p} \sim 10^5 \text{ GeV} \quad ; \quad M_p \sim 10^{19} \text{ GeV} \tag{12}$$

we find

$$\Lambda = \sqrt{\mu M_p} \sim 10^{12} \text{ GeV}, \tag{13}$$

$$\Lambda^2 M_p \sim 10^{43} \text{ GeV}^3 \lesssim \tilde{\Lambda}^3 \lesssim 10^{-4} \Lambda M_p^2 \sim 10^{46} \text{ GeV}^3, \tag{14}$$

so we can take, for example, $\tilde{\Lambda} \sim 10^{15} \text{ GeV}$, and then $\sqrt{F_s} \sim 10^6 \text{ GeV}$, $m_Q \sim m_f \sim 10^7 \text{ GeV}$ and $\epsilon \sim 10^{-5}$.

Although the range in (14) might appear very narrow, in fact the situation is better. First, by including coupling constants and various factors of order one in (1) the range in (14) can be expanded. Second, note that there are no phenomenological problems if the inequalities (14) are close to being saturated (hence we used the symbol \lesssim). If the first one is close to being saturated, the messenger fields could be lighter than m_f , but there is nothing wrong with that, while the second inequality already includes a safety factor of 100.

Acknowledgments

We would like to thank M. Dine for useful comments. This work was supported in part by grant #DE-FG02-90ER40542. The work of O.A. was supported in part by the Israel-U.S. Binational Science Foundation, by the Israel Science Foundation, by the European network MRTN-CT-2004-512194, by a grant from the G.I.F., the German-Israeli Foundation for Scientific Research and Development, by Minerva, and by a grant of DIP (H.52).

References

- [1] E. Witten, *Dynamical breaking of supersymmetry*, *Nucl. Phys.* **B 188** (1981) 513.
- [2] M. Dine, W. Fischler and M. Srednicki, *Supersymmetric technicolor*, *Nucl. Phys.* **B 189** (1981) 575.
- [3] S. Dimopoulos and S. Raby, *Supercolor*, *Nucl. Phys.* **B 192** (1981) 353.
- [4] M. Dine and W. Fischler, *A phenomenological model of particle physics based on supersymmetry*, *Phys. Lett.* **B 110** (1982) 227.
- [5] C.R. Nappi and B.A. Ovrut, *Supersymmetric extension of the $SU(3) \times SU(2) \times U(1)$ model*, *Phys. Lett.* **B 113** (1982) 175.
- [6] L. Alvarez-Gaumé, M. Claudson and M.B. Wise, *Low-energy supersymmetry*, *Nucl. Phys.* **B 207** (1982) 96.
- [7] S. Dimopoulos and S. Raby, *Geometric hierarchy*, *Nucl. Phys.* **B 219** (1983) 479.
- [8] M. Dine and A.E. Nelson, *Dynamical supersymmetry breaking at low-energies*, *Phys. Rev.* **D 48** (1993) 1277 [[hep-ph/9303230](#)].
- [9] M. Dine, A.E. Nelson and Y. Shirman, *Low-energy dynamical supersymmetry breaking simplified*, *Phys. Rev.* **D 51** (1995) 1362 [[hep-ph/9408384](#)].
- [10] M. Dine, A.E. Nelson, Y. Nir and Y. Shirman, *New tools for low-energy dynamical supersymmetry breaking*, *Phys. Rev.* **D 53** (1996) 2658 [[hep-ph/9507378](#)].
- [11] G.F. Giudice and R. Rattazzi, *Theories with gauge-mediated supersymmetry breaking*, *Phys. Rept.* **322** (1999) 419 [[hep-ph/9801271](#)].
- [12] K. Intriligator, N. Seiberg and D. Shih, *Dynamical SUSY breaking in meta-stable vacua*, *JHEP* **04** (2006) 021 [[hep-th/0602239](#)].

- [13] S. Franco and A.M. . Uranga, *Dynamical SUSY breaking at meta-stable minima from D-branes at obstructed geometries*, *JHEP* **06** (2006) 031 [[hep-th/0604136](#)].
- [14] H. Ooguri and Y. Ookouchi, *Landscape of supersymmetry breaking vacua in geometrically realized gauge theories*, *Nucl. Phys.* **B 755** (2006) 239 [[hep-th/0606061](#)].
- [15] R. Kitano, *Dynamical GUT breaking and μ -term driven supersymmetry breaking*, *Phys. Rev.* **D 74** (2006) 115002 [[hep-ph/0606129](#)].
- [16] T. Banks, *Remodeling the pentagon after the events of 2/23/06*, [hep-ph/0606313](#).
- [17] R. Kitano, *Gravitational gauge mediation*, *Phys. Lett.* **B 641** (2006) 203 [[hep-ph/0607090](#)].
- [18] A. Amariti, L. Girardello and A. Mariotti, *Non-supersymmetric meta-stable vacua in SU(N) SQCD with adjoint matter*, *JHEP* **12** (2006) 058 [[hep-th/0608063](#)].
- [19] M. Dine, J.L. Feng and E. Silverstein, *Retrofitting O’Raifeartaigh models with dynamical scales*, *Phys. Rev.* **D 74** (2006) 095012 [[hep-th/0608159](#)].
- [20] M. Dine and J. Mason, *Gauge mediation in metastable vacua*, [hep-ph/0611312](#).
- [21] R. Kitano, H. Ooguri and Y. Ookouchi, *Direct mediation of meta-stable supersymmetry breaking*, [hep-ph/0612139](#).
- [22] H. Murayama and Y. Nomura, *Gauge mediation simplified*, [hep-ph/0612186](#).
- [23] C. Csáki, Y. Shirman and J. Terning, *A simple model of low-scale direct gauge mediation*, [hep-ph/0612241](#).
- [24] H. Murayama, *A model of direct gauge mediation*, *Phys. Rev. Lett.* **79** (1997) 18 [[hep-ph/9705271](#)].
- [25] S. Dimopoulos, G.R. Dvali, R. Rattazzi and G.F. Giudice, *Dynamical soft terms with unbroken supersymmetry*, *Nucl. Phys.* **B 510** (1998) 12 [[hep-ph/9705307](#)].
- [26] M.A. Luty, *Simple gauge-mediated models with local minima*, *Phys. Lett.* **B 414** (1997) 71 [[hep-ph/9706554](#)].
- [27] S. Dimopoulos, G.R. Dvali and R. Rattazzi, *A simple complete model of gauge-mediated SUSY-breaking and dynamical relaxation mechanism for solving the μ problem*, *Phys. Lett.* **B 413** (1997) 336 [[hep-ph/9707537](#)].
- [28] I. Affleck, M. Dine and N. Seiberg, *Dynamical supersymmetry breaking in four-dimensions and its phenomenological implications*, *Nucl. Phys.* **B 256** (1985) 557.
- [29] N. Seiberg, *Electric - magnetic duality in supersymmetric nonabelian gauge theories*, *Nucl. Phys.* **B 435** (1995) 129 [[hep-th/9411149](#)].
- [30] N. Seiberg, *Exact results on the space of vacua of four-dimensional SUSY gauge theories*, *Phys. Rev.* **D 49** (1994) 6857 [[hep-th/9402044](#)].
- [31] A.E. Nelson and N. Seiberg, *R symmetry breaking versus supersymmetry breaking*, *Nucl. Phys.* **B 416** (1994) 46 [[hep-ph/9309299](#)].