Breaking SUSY with lots of singlets

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Technion

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or:

O'Raifeartaigh-like SB minima in chiral and non-chiral theories

1. Singlet-aided SB
2. ISS-like SB (rank condition(s))

Motivation

- sadly: no experimental motivation

  don't need fancy measures of tuning to know that supersymmetry doesn't work very well for EWSB

- flavor–not really that constraining: there is room for (measurable!) generation-dependent spectra consistent with all low-energy bounds

- trouble is really EW sector

dynamical supersymmetry breaking, gauge mediation are beautiful ideas

?? last days of Pompeii so we should al least have some fun..

surprisingly: very few (**one??**) truly successful GMSB models

Dine-Nelson-Shirman, Dine-Nelson-Nir-Shirman

models with very different spectra?
(realizing GGM, broader–gauge messengers, ??)

DNNS can even accomodate flavor

flavored DNNS

Shadmi-Szabo, arXiv:1103.0292 [hep-ph]

- take DNNS model with matter-messenger couplings
  (Higgs $\longrightarrow$ messenger)
  flavor disaster ?? **no!**
- must remember that we don't understand SM Yukawas:
  if Yuwakas explained by something, that somewthing also controls matter-messenger couplings!
- can generate viable models with selectron-smuon mass splittings, mixings..

New minima for GMSB?

- moral of ISS:
  local SB minima exist in many (extremely simple) theories

  Intriligator-Seiberg-Shih

  would guess that local SM minima are generic: go back and re-examine known models for such minima

  indeed for “practical applications” local SB minima are all we care about

  if you count GMSB models as a practical application..

- singlets used to be badmouthed for theory reasons*

  e.g.*: "Gauge mediation without fundamental singlets," **Shadmi '97**

$$Sq\bar{q} \rightarrow \frac{B}{M_P^n} q\bar{q}$$

  with B baryon of SB SU(N)×SU(N-1) non-renorm models

  Poppitz Shadmi Trivedi '96

  with $\langle B \rangle \neq 0$, $\langle F_B \rangle \neq 0$

- but for practical applications ultimate goal is direct gauge mediation:
  gauge some global symmetries → singlets charged

- one of the most frustrating aspect of SB: no organizing principle
  still dont have one
  yet: general recipe for obtaining SB local minima from s-confining theories using singlets
  - generalizing ITIY

    Intriligator-Thomas, Izawa-Yanagida
  - further generalizations??

interim summary:

- general strategy for looking for SM vacua: lower standards (allow local minima, singlets)
- as will see, end up with susy breaking models (not just local SB)

s-confining theories:

a good place to look: the *s*-confining theory bible

Scaki-Schmaltz-Skiba

- *s*-confining theories are well understood:
  moduli space = classical moduli space, parametrized by gauge invariants O_i

more in J. Mason's talk after break

- origin is part of moduli space

singlet-aided supersymmetry breaking

Y. Shadmi and Y. Shirman 1105.????

General recipe:

- take s-confining theory: gauge invariants O_i

Seiberg; Scaki-Schmaltz-Skiba

- add a singlet S_i for each O_i but one ($\tilde{O}$) (preferably highest dim)
- with

$$W = S_i O_i + \tilde{f}\tilde{O}$$

$\longrightarrow$ calculable SB min near origin

- no SUSY vacua

General recipe cont':

- SB scale, other dim-ful parameters naturally small, arise from non-renorm operators

$$\propto \ r_{\rm UV}^n = \left(\frac{\Lambda}{M_{\rm UV}}\right)^n$$

- calculable by virtue of (naturally) small parameters
  [in some models, don't need to take any parameter to be small "by hand"]

example:

s-confining SU(2N) with AS and four extra flavors

may seem complicated but simple

Classical theory

- fields: A (AS), $\bar{Q}_{a=1\ldots 2N}$, $Q_{i=1\ldots 4}$
- gauge invariants:

  $M_{ia} = Q_i \cdot \bar{Q}_a, \quad P_{ab} = A\bar{Q}_a\bar{Q}_b$

  $Y_{ij} = A^{N-1}Q_iQ_j, \quad X = A^{N-2}Q^4, \quad \tilde{A} = A^N, \quad B = \bar{Q}^{2N}$
- add singlets for all but B $+$ superpotential

  (written in terms of gauge invariants for simplicity)

$$W_0 = \lambda_M \mathbf{S_M^{ia}} M_{ia} + \frac{\lambda_P}{M_{\rm UV}} \mathbf{S_P^{ab}} P_{ab} + \frac{\lambda_A}{M_{\rm UV}^{N-2}} \mathbf{S_A} \tilde{A} + \frac{\lambda_Y}{M_{\rm UV}^{N-1}} \mathbf{S^{ij}} Y_{ij} + \frac{\lambda_X}{M_{\rm UV}^{N}} \mathbf{S_X} X + \frac{\lambda_B}{M_{\rm UV}^{2N-3}} B$$

Classical theory cont'

- gets rid of all flat directions but singlets
- [practical purposes:
  singlet terms don't break global symmetries]

Quantum theory

described by gauge invariants subject to

$$W_{dyn} = \frac{1}{\Lambda^{4N-1}} \left[\left(\tilde{A} M^4 P^{N-2} + Y M^2 P^{N-1} + X P^N \right) + B \left(\tilde{A} X + Y^2 \right) \right]$$

high powers of M, P, no M, P

"factorization" very generic

Quantum theory cont

- theory confines: singlet terms $\rightarrow$ masses for all gauge invariants except B (near origin)
- defining $r_{\mathrm{UV}} = \Lambda / M_{\mathrm{UV}}$

$$
\begin{array}{ll}
M_{ia} & m \sim \lambda_M \Lambda \\
P_{ab} & m \sim \lambda_P \, \mathbf{r}_{\mathrm{UV}} \, \Lambda \\
\tilde{A} & m \sim \lambda_A \, \mathbf{r}_{\mathrm{UV}}^{\mathbf{N-2}} \, \Lambda \\
Y_{ij} & m \sim \lambda_Y \, \mathbf{r}_{\mathrm{UV}}^{\mathbf{N-1}} \, \Lambda \\
X & m \sim \lambda_X \, \mathbf{r}_{\mathrm{UV}}^{\mathbf{N}} \, \Lambda
\end{array}
$$

- and

$$f_B = \lambda_B \, \mathbf{r}_{\mathrm{UV}}^{\mathbf{2N-3}} \, \Lambda^2 \ \sim m_X m_A \sim m_Y^2$$

O'Raifeartaigh model

up to non-renorm terms involving M, P:

$$\begin{aligned} W &= S_M M + S_P P \\ &+ B[\tilde{A}X + Y^2 + f_B] + S_X X + S_Y Y + S_A \tilde{A} \end{aligned}$$

O'Raifeartaigh model

local minimum with M, P, S_M, S_P zero

$X, Y, \tilde{A}, B$ determined by O'Raifeartaigh model

O'Raifeartaigh model cont'

$$W = B[\tilde{A}X + Y^2 + f_B] + m_X S_X X + m_Y S_Y Y + m_A S_A \tilde{A}$$

- recall $m_X m_A \sim m_Y^2 \ll f_B$
- B is flat direction of potential
- to simplify things (not really necessary) take $\lambda_A < 1$ so $m_A m_X < m_Y^2$, integrate out Y
- CW:

$$\begin{aligned} B &= 0 \\ A &= \lambda_A^{-1/2}\, r_{\rm UV}^{N-1/2} \Lambda \ll \Lambda \\ X &= \lambda_A^{1/2}\, r_{\rm UV}^{N-5/2} \Lambda \ll \Lambda \end{aligned}$$

Why calculable

- NR superpotential terms indeed negligible: all VEVs much smaller than Λ
- Kahler potential:

$$K = B^\dagger B \left[1 + g_B \left(\frac{M}{\Lambda}, \ldots, \frac{B}{\Lambda}, \frac{\lambda_M S_M}{\Lambda}, \ldots \right) \right] + \ldots$$

with g_B some function
$\longrightarrow$ potential for B near origin

$$V \sim f_B^2 \left(1 + \alpha \frac{B^\dagger B}{\Lambda^2} + \ldots \right)$$

so non-calculable contribution to mass $\sim f_B^2/\Lambda^2$.

Calculability cont'

- Coleman Weinberg contribution

$$m_B^2 \sim \frac{1}{16\pi^2} \frac{(m_A m_X)^2}{f_B}$$

- so

$$\frac{\mathrm{non-calculable}}{\mathrm{calculable}} \sim 16\pi^2 \, r_{\mathrm{UV}}^{2N-5} \ll 1$$

in other models can have $m_A m_X > f_B$ with

$$m_B^{2\,(\mathrm{Coleman-Weinberg})} \sim \frac{1}{16\pi^2}\, f_B$$

so things are even simpler:

$$\frac{\mathrm{non-calculable}}{\mathrm{calculable}} \sim 16\pi^2\, \frac{f_B}{\Lambda^2} \ll 1$$

ISS-like vacua in chiral models

Y. Shadmi 1105.????

example: SU(6) with AS A_{ijk} and four flavors

Classical theory

- fields: A_{ijk} (AS), $\bar{Q}_{a=1...4}$, $Q_{i=1...4}$
- gauge invariants:
  $M_{ia}^{(0)} = Q_i \, \bar{Q}_a \quad M_{ia}^{(2)} = Q_i \, A^2 \, \bar{Q}_a,$
  $B_i^{(1)} = (A \, Q^3)_i \qquad \bar{B}_a^{(1)} = (A \, \bar{Q}^3)_a$
  $B_i^{(3)} = (A^3 \, Q^3)_i \qquad \bar{B}_a^{(3)} = (A^3 \, \bar{Q}^3)_a$
  $T = A^4$

Quantum theory

described by gauge invariants with

$$W_{dyn} = M^{(0)} B^{(1)} \bar{B}^{(1)} T + M^{(2)} (M^{(0)})^3 T + M^{(0)} \left(M^{(2)}\right)^3$$
$$+ M^{(0)}_{ia} B^{(3)}_i \bar{B}^{(3)}_a + M^{(2)}_{ia} \left(B^{(3)}_i \bar{B}^{(1)}_a + B^{(1)}_i \bar{B}^{(3)}_a \right)$$

add

$$W_0 = \mu_0 \delta_{ia} Q_i \, \bar{Q}_a + \frac{\lambda}{M_{\rm UV}} \delta_{ia} Q_i \, A^2 \, \bar{Q}_a + \frac{\lambda}{M_{\rm UV}^2} \, S \, A^4$$

Quantum theory cont'

in IR: neglecting NR-terms

$$
\begin{aligned}
W &= M_{ia}^{(0)} \left(B_i^{(3)} \bar{B}_a^{(3)} + f_0 \delta_{ia} \right) \\
&+ M_{ia}^{(2)} \left(B_i^{(3)} \bar{B}_a^{(1)} + B_i^{(1)} \bar{B}_a^{(3)} + f_2 \delta_{ia} \right) + mST
\end{aligned}
$$

- rank-condition breaking
- natuarlly small $f_2 \propto r_{\rm UV}$, $m \propto r_{\rm UV}^2$

To conclude:

- indeed many new models
- simplest examples: no R breaking: can modify O'Raifeartaigh model itself

  Shih

  need small parameters (by hand)
- singlets are nice:
  - straightforawrd procedure of getting SB: lift classical directions, give mass near origin
  - don't break global symmetries
  - (lots) of candidates for messengers