Retrofitting O'Raifeartaigh Models with Dynamical Scales

M. Dine, J. Feng, E.S.
hep-th/0608159

Low energy SUSY is an interesting possibility → much work on spontaneous breaking and its transmission to the SSM.

'tHooft/Wilson naturalness suggests Dynamical SUSY Breaking (DSB)

- Small scales (EW hierarchy) explained via dimensional transmutation Witten '81

$$\Lambda \sim \mu_0 e^{-\frac{1}{b_0 g^2}}$$

Exponential hierarchy

Much Interesting Model Building over the years to implement DSB:

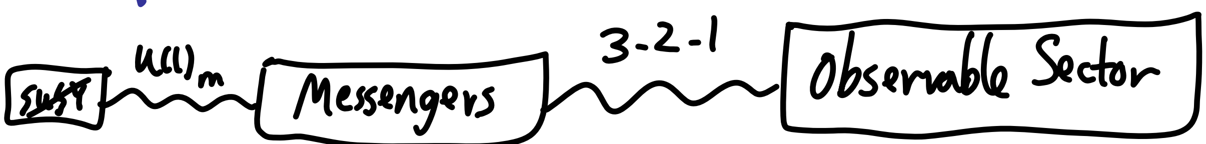
Reviews: Giudice/Rattazzi, Shadmi/Shirman, Luty, Poppitz/Trivedi

'81 Witten DSB

'82 Dine Fischler ...

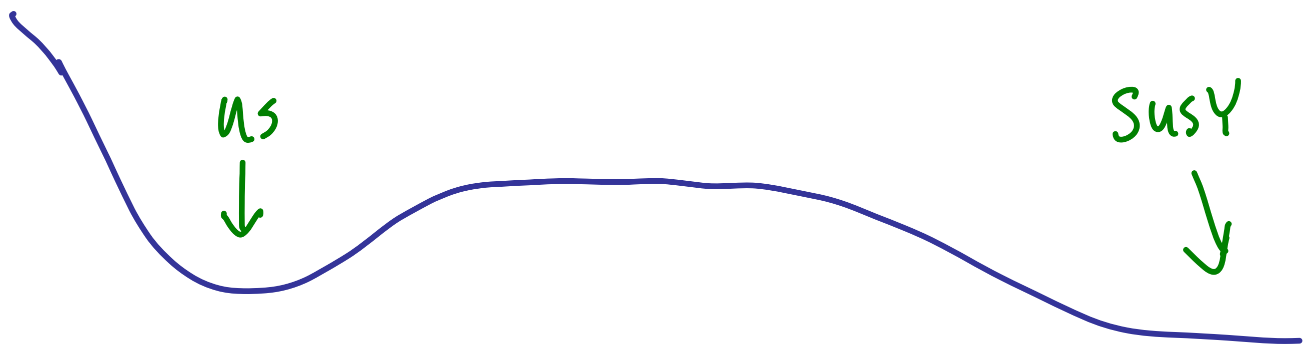
'84 Affleck Dine Seiberg

'95 Dine Nelson Nir Shirman ...



'96 - '97 Agashe Arkani-Hamed Binetruy Dimopoulos Dudas Dvali Giudice Izawa Luty March-Russell Murayama Nomura Pomarol Poppitz Randall Rattazzi Shirman Trivedi ...

- Metastability: Need not impose that global min. break SUSY
- "Direct Mediation": SUSY can be transmitted to SSM by messengers which also participate in the SUSY dynamics



Requiring only metastability is a very useful simplification (Dimopoulos et al '97, Murayama '97, Luty '97 ...)

as we saw more recently in stabilizing moduli (ES '01, KKLT '03...) and analyzing their dynamics (Bousso-Polchinski, [FMSW] '00)

and in vacuum structure of large-N gauge theories (Kachru-Pearson-Verlinde '01)

and $N_c+1 \le N_f < \frac{3}{2} N_c$ SQCD (Intriligator-Seiberg-Shih '06)

This talk: trivial method for DSB

1) Start with model of perturbative ~~SUSY~~, such as O'Raifeartaigh and/or Fayet model, whose small input parameters m_i break an R-symmetry which would be restored if m_i transform like the superpotential.

2) Couple to a SUSY-preserving sector with a dynamically small operator VEV, e.g. pure $N=1$ $SU(2)$ with gauge field strength W_α, scale Λ.

Replace $m_i \to \frac{W_\alpha W^\alpha}{M_*^n} \sim \Lambda^3/M_*^n$,

$M_* \sim$ e.g. M_{GUT}, M_{KK}, ...

writing most general action respecting symmetries

Preserves local ~~SUSY~~ minimum.

e.g. O'Raifeartaigh models:

General Structure: $W = \sum_{i=1}^{N} z_i \, f_i(\varphi_{a=1\ldots n})$

- $N > n \Rightarrow$ ~~SUSY~~ generically
- classical flat direction lifted by Coleman-Weinberg potential cf Dine–Fischler '82

Simple and effective, but...

Problems:

- Form of W not enforced by symmetries
- Small dimensionful parameters input by hand.

(• Need messengers, R-breaking -cf gauge mediation)

Model **Building Code**

1) **All terms consistent with the symmetries must be included in the effective action**
2) **Any small parameters must be generated dynamically**
3) **The model must produce a spectrum of particles and interactions consistent with known phenomenology.**

By order of Inspector G. 'tHooft and Superintendent Wilson, any model not satisfying requirements (1)-(3) must be retrofitted to do so.

Simple Example:

$\eta, \tilde{\eta} \equiv$ messengers

Retrofit: replace with $\frac{W_\alpha^2}{M_*} Z_2$

$$W = Z_1 \frac{Q^3}{3M_*} + Z_2 \left(\frac{Q^2}{2}\left[1 + \lambda_1 \frac{Z_2}{M_*}\right] - \frac{\mu^2}{2} + \frac{Q \eta \tilde{\eta}}{M_*} + Q \eta \tilde{\eta} + \lambda_2 \frac{(\eta\tilde{\eta})^2}{M_*} - \frac{1}{4} g^2 W_\alpha^2 \right)$$

The model respects the following symmetries:

	W	Q	Z_1	Z_2	W_α	$(\eta\tilde{\eta})$
$\mathbb{Z}_{2N}$	2	1	-1	0	1	1
Approximate $U(1)$ (broken by M_*-suppressed operators)	2	0	2	2	1	2

The original O'R model

$$W = Z_1 \frac{\Phi^3}{3M_*} + Z_2\left(\frac{\Phi^2}{2} - \frac{\mu^2}{2}\right)$$

has a classical flat direction in Z, with Φ stabilized at

$$\Phi_0 \simeq \mu^2 - \frac{2\mu^4}{3M_*^2} \Rightarrow F_{Z_1} \simeq \frac{\mu^3}{3M_*}, \; F_{Z_2} \simeq -\frac{\mu^4}{3M_*^2}$$

Integrating out fluctuations $\delta\Phi$ gives Coleman-Weinberg potential stabilizing $Z = Z_0 = 0$

$$\mathcal{L}_{\delta\Phi^2} = \delta\Phi\delta\bar{\Phi}\underbrace{\left(\mu^2 + |Z_2|^2\right)}_{= M_F^2} + \underbrace{\left(\delta\Phi_1^2 - \delta\Phi_2^2\right)\frac{\mu^4}{3M_*^2}}_{\text{~~SUSY~~}}$$

$$\Delta V = \mathrm{Tr}\log\left[\left(\mu^2 + |Z_2|^2 + p^2\right)^2 - \left(\frac{\mu^4}{3M_*^2}\right)^2\right] - \mathrm{Tr}\log\left[\left(\mu^2 + |Z_2|^2 + p^2\right)^2\right]$$

$$\Delta V = \frac{1}{32\pi^2}\left(\frac{\mu^4}{3M_*^2}\right)^2 \log\left[\left(\mu^2 + |Z_2|^2\right)/M_*^2\right]$$

Back to the retrofit model w/messengers

Integrate out SU(2) sector →

$$W = \frac{Z_1 \mathcal{Q}^3}{3M_*} + \Lambda^3 e^{-\frac{12 Z_2}{b_0 M_*}} + \lambda_2 \frac{(\eta\tilde{\eta})^2}{M_*}$$
$$+ Z_2\left(\frac{\mathcal{Q}^2}{2}\left[1 + \lambda_1 \frac{Z_2}{M_*}\right] + \frac{\mathcal{Q}\eta\tilde{\eta}}{M_*}\right) + \mathcal{Q}\eta\tilde{\eta}$$

- $\frac{\mu^2}{2}$ replaced by $\frac{12}{b_0 M_*}\Lambda^3$
- Messenger loops subleading in Coleman-Weinberg potential
- Local minimum near $Z = 0 = \eta\tilde{\eta}$, $\mathcal{Q} = \mathcal{Q}_0$ preserved: in self-consistent solution, higher orders in Z/M_* yield tiny shift in Z
- Global SUSY minimum introduced far away $(|Z| \to \infty)$

This example provides a complete model of gauge mediation

$$W_{messenger} = \phi \eta \tilde{\eta} + \frac{Z_2}{M_*} \phi \eta \tilde{\eta}$$

$$\langle \phi \rangle \simeq m_{\eta\tilde{\eta}} \simeq \mu$$

$$F_{effective} = \frac{\phi}{M_*} F_{Z_2} \simeq -\frac{\mu^5}{3M_*^3}$$

$$m_{\substack{SSM \\ gauginos}} \sim \frac{g_{SM}^2}{16\pi^2} \frac{F_{eff}}{m_{\eta\tilde{\eta}}} \sim \frac{g_{SM}^2}{16\pi^2} \frac{\mu^4}{M_*^3}$$

e.g. $M_* = M_{GUT} \Rightarrow m_{\eta,\tilde{\eta}} \sim 10^{13}$ GeV

intermediate/high scale gauge mediation (beats gravity)

Remarks:

- The method applies more generally
  - e.g. gravity mediation: no $\eta, \tilde{\eta}$, just include coupling $\int d^2\theta \, \frac{Z_2}{M_*} \underbrace{(W_\alpha^{SSM})^2}_{\text{SSM gauginos}}$
  - No obvious obstruction to gauge mediation with low scale messenger masses (don't yet have explicit examples either)
- Witten index can be nonzero, and model need not be chiral, to obtain viable metastable solutions

  cf KPV, ISS

A second class of examples involves the Fayet model, and provides direct mediation in that messengers $\eta, \tilde{\eta}$ play leading role in CW potential.

$$W = \eta X \tilde{\eta} + M^2 X - \frac{\lambda}{3} X^3$$

$$D^2 = \left(e|\eta|^2 - e|\tilde{\eta}|^2 - r\right)^2 \leftarrow U(1) \text{ gauge symm.}$$

$$V(X,\eta,\tilde{\eta}) = \left(|\eta|^2 + |\tilde{\eta}|^2\right)|X|^2 + |\eta\tilde{\eta} + M^2 - \lambda X^2|^2 + \tfrac{1}{2}D^2 + \Delta V_{cw}$$

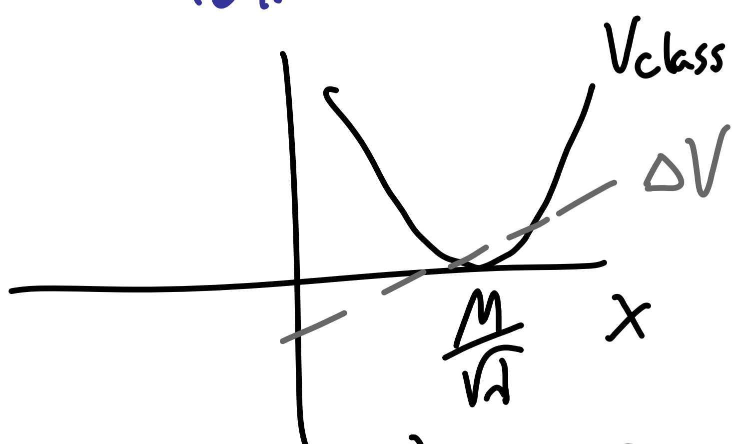
Expand about $X_0^2 = M^2/\lambda$, $\eta = 0 = \tilde{\eta}$ and consider $eD \ll X_0^2$ so $\eta, \tilde{\eta}$ are heavy, non-tachyonic about this point. Will find self-consistently $eD_0 \gg F_X$, so eD_0 is the leading ~~SUSY~~ effect contributing to ΔV_{cw}.

$$\Delta V_{CW} \sim \mathrm{Tr}\log\left(\left(|X|^2+p^2\right)+e^2D_0^2\right) \quad \eta \text{ loop}$$

$$+\,\mathrm{Tr}\log\left(\left(|X|^2+p^2\right)-e^2D_0^2\right) \quad \tilde{\eta} \text{ loop}$$

$$-\,\mathrm{Tr}\log\left(|X|^2+p^2\right)^2+\mathcal{O}\left(F^2\right)$$

$$\rightarrow \Delta V(X) = \frac{e^2D_0^2}{16\pi^2}\log\frac{|X|^2}{M_*^2} + \text{subleading}$$



$$\rightarrow X_0^2 \simeq \frac{M^2}{\lambda} - \frac{e^2D_0^2}{32\pi^2\lambda M^2} \qquad F_X \simeq \frac{e^2D_0^2}{32\pi^2M^2}$$

self-consistent: $eD_0 \ll M^2 \Rightarrow F \ll eD_0$

so D-breaking does dominate.

So far, we have a small input scale $eD_0 \sim er$. We can retrofit to obtain the small number dynamically.

First, use Fayet model to translate this into a superpotential term:

- add $a, \tilde{a}$ of charge ± 1 under $U(1)$
- add $\Delta W = m_a a \tilde{a}$

$$\Rightarrow V = \frac{1}{2}\big(e|a|^2 - e|\tilde{a}|^2 + \underbrace{0}_{\eta,\tilde{\eta}} - r\big)^2 + m_a^2\left(|a|^2 + |\tilde{a}|^2\right)$$

For $er > m_a^2$, $eD_0 = m_a^2$

- Can now couple in SU(2)

$$m_a a\tilde{a} \to \frac{W_\alpha W^\alpha}{M_*^2} a\tilde{a},$$ enforced by an R symmetry.

$\Rightarrow$ eD_0 from above analysis is rendered dynamically small.

- Imposing a $\mathbb{Z}_2$ symmetry leads to a model satisfying 't Hooft naturalness (see paper) with

$$F_X \sim \Lambda^9 / M_*^7 \qquad X_0 \sim M$$

$M_* \sim M_{GUT} \sim 10M \to$ TeV gauginos, high-scale messengers

Remarks / Future directions :

- Natural DSB [and direct mediation] straightforward to obtain (despite some lingering lore that realizing DSB is complicated). Only need '80s ingredients...

- Can also retrofit more intricate models
  e.g. SQCD/ISS Schmaltz/Sundrum

- Models with low-energy gauge fields

- Lower messenger masses ?

- Cosmology — enhanced symmetries & light fields plausibly help the universe settle into ~~SUSY~~ vacua
  cf Wacker talk, Dine et al, moduli trapping

- Do these simple EFTs embed into simple/compelling string compactifications?

- Of course from the "top down", low energy SUSY is a strong assumption: almost every string compactification breaks SUSY at $\gtrsim M_{KK}$, and has the ingredients (O-planes & equivalents, fluxes, curvature) necessary for stabilization

- In above examples, used discrete R-symmetries, which are 't Hooft/Wilson natural, but still special choice?

cf Dine, Thomas, ...