THE BIG PICTURE

WE WANT TO WRITE DOWN MODELS OF REALISTIC SUSY/MG.
THE SUSY GAUGE RULE (ST: M^2 = 0) FORCES A MODULAR STRUCTURE.

MSSM — messengers — SUSY

↑

eq. gauge mediation ...

THE QUESTION IS HOW TO BUILD MODELS FOR THIS SECTOR.

↓

Not as easy as you'd naively think!

eg. 1st model of SUSY is often drafter直辖市

- 3 fields
- Special superpotential

I have to work hard to kill SUSY VACUA!

and SUSY is non-generic (Bushing vacua)

A NICE IDEA IS DYNAMICAL SUSY/MG.

→ DSB — MSSM

BREAK SUSY VIA STRONG DYNAMICS

→ NAbelian, asymmetric free

SUSY SCALE GENERATED BY DIMENSIONAL TRANSLATION

\[
\mathcal{L} = \frac{b}{2\pi i} \log \lambda \rightarrow \lambda = |\lambda| e^{i\theta_m/6}
\]

\[
\frac{4\pi i}{q^2} + \frac{\theta_m}{2\pi}
\]

\[
\lambda \sim \Lambda e^{-\frac{8\pi^2}{6g_0}}
\]

This gives a natural TeV-scale SUSY.
BUT DYNAMICAL SUSY IS EVEN MORE 'NON-GENERIC' THAN OTHER WAYS OF BREAKING SUSY!

- MODELS END UP RATHER COMPLICATED, RED. TRIVIAL SUSY ON, SPECIAL STRUCTURE
- SUSY W (SUSY) HAS ITS OWN PROBLEMS

Strong coupling — "calculability" — use duality

WITTEN INDEX = N

⇒ in low dim. large vacuums, SUSY IS SYM
⇒ IN SUSY VACUA

HISTORICALLY: WITIEN'S CALCULATION OF HIS INDEX WAS THE "NAIL IN THE COFFIN" FOR DYNAMICAL SUSY BREAKING.

A famous exceptional cases, e.g. (3-2), (4-1), ITY models
but it seemed really difficult to construct a DSB sector.

WHAT MAKES SUSY 'GENERIC'?

'no 'fine tuning' or 'special relations' among model parameters.'

USEFUL NOTION OF 'GENERICITY':

'GENERIC' ⇒ n EQUATIONS FOR n UNKNOWNS
GENERALLY HAVE A SOLUTION.

NELSON-SEIBERG R-SYMMETRY THM (WEP 9/93 299)

SU(N) ⇒ R SYMMETRY
SUSY ⇒ SU(N)

(R IS NECESSARY FOR SUSY)
(SUSY IS SUFFICIENT FOR SUSY)

ASSUMPTIONS: GENERIC EFF, CALCULABLE (LAW E THM = WESS-ZUMINO, NO YM)

P1/ R[W] = 2

(W φ, ..., φ n ) = φ 1 φ 2 φ 3 , ..., φ n φ 1 φ 2 φ 3

W = 0 ⇒ W = 0 ⇒ φ 1 φ 2 φ 3 , φ 4 , ..., φ n φ 1 φ 2 φ 3 = 0 ⇒ W = 0

⇒ n EQUATIONS FOR (n-1) UNKNOWNS
OVERCONSTRAINED: GENERICALLY NO SOLUTION ⇒ SUSY
PROBLEMS w/ R SYMMETRY

1. SU(3) → U(N) R SYMMETRY
2. NONZERO GIMMICHRO MASS → R (WGA BREAKS R)
3. IF SSB R → MASSLESS GOLDSTONE

R SYMM EXPLICITLY BROKEN ... BUT THEN ARE SUCH VACUA!

QUALITY HATES CONTINUOUS DIM.
IF LIKES TO BREAK THEN EXPLICITLY
→ MASS TO GOLDSTONE, MAY NOT BE ENOUGH

AS SUCH VACUA IN A 'GENERIC' THEORY!

LEMONADE OUT OF LEMONS:

METASTABLE SUSY

1. GENERIC → CAN USE FRAMEWORK OF SQCD
2. EXPLICIT R, REMIND AS ACCIDENTAL SYMM IN LOW-E THY
3. SMALL PARAMETER ε WHICH PARAMETERIZES
   "EXPLICIT R BREAKING"
   "SEPARATION OF SUSY & SUSY VACUA IN FIELD SPACE"

BUT WE STILL HAVE POTENTIAL PROBLEMS W/ CALCULABILITY

SQCD IN ASYMPTOTICALLY FREE REGIME
→ IR CONFING ... ? LOW E DOF.

TRICK: USE SEIBERG DUALITY!

**ELECTRIC THY**

SU(N) w/ q, q̄

W = 0
ASYMPTOTICALLY FREE (F < 3N)
IR FREE FOC. (F > 3N)

**SEIBERG**

SU(N)
SU(F)
SU(F)

**MAGNETIC THY**

SU(N) w/ b, b̄, φ

Wm = φbφ̄

IR FREE (F < 3N)

SU(N)
SU(F)
SU(F)

ASYMPTOTIC FREE (F > 3N)
**Selberg Duality:**

\[ \Lambda \quad \text{SAME IR Scet} \quad \Lambda \]

\[ \text{Electric } \text{SU}(n) \quad \text{U(1)} \quad \text{UV} \quad \text{Thy} \]

\[ \text{Magnetic } \text{SU}(n) \quad \text{IR} \quad \text{Thy} \]

So now we have a region where we can use tools to find metastable such vacua in a way where we have control of the UV & IR.

**Strategy:**

1. Write down IR model w/ tree-level softening
   - This will be our SU(n) magnetic theory, but not yet gauged.
2. Gauge the theory - Metastable vacuum
3. Show results are insensitive to UV theory details.
4. Write dynamical that

**Naive Model I**

\[ W = \frac{1}{2} \text{Tr} \bar{\psi} i \gamma^\mu \partial_\mu \psi - \frac{1}{2} m^2 \text{Tr} \phi \]

\[ k = \text{Qau.} \]

<table>
<thead>
<tr>
<th>SU(n)</th>
<th>SU(F)</th>
<th>SU(F)</th>
<th>U(1)A</th>
<th>U(1)</th>
<th>U(1)E</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{g} )</td>
<td>0</td>
<td>0</td>
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<tr>
<td>( \bar{g}^\prime )</td>
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<td>1</td>
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<tr>
<td>( \bar{\phi} )</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-2</td>
<td>2</td>
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</tbody>
</table>

\[ \Delta W = -\frac{1}{2} m^2 \text{Tr} \phi \]

Breaking gauge \( \text{SU(n)} \rightarrow \text{SU}(\frac{n}{2}) \times \text{SU}(\frac{n}{2}) \times \text{U(1)}A \times \text{U(1)}E \)

This term is associated with mass of electric quarks in the UV theory. (Is related, p.41)
**BY THE RANK CONDITION**

This is just one of many ways to break SUSY at tree-level.

**F-term breaking:** if \( F \neq 0 \Rightarrow W \sim |F|^2 \neq 0 \Rightarrow \text{SUSY} \)

\[
-F_\phi = h \psi \phi^T + h |\phi|^2 \quad \text{(matrix eqn)}
\]

Rank \( n \) \quad Rank \( F > n \) \quad (~ 1 \text{fp})

Thus the 1st & 2nd terms cannot cancel completely.

\[
V \sim (F - n) |h| |\phi|^2 \quad \Rightarrow \text{SUSY}
\]

**ISS:** Consider vacuum that preserves maximum unbroken global symmetries: (up to flavor rot.)

\[
\Phi_0 = 0 \quad Y = \Phi^T = \begin{pmatrix} 1 & 1_{1 \times n} \end{pmatrix}
\]

(\text{near origin})

Calculation: Expand about this vacuum.

\[
V = |W_\Phi|^2 + |W_\Psi|^2 + |W_\phi|^2
= |\phi|^2 + |\Phi|^2 + |\Psi|^2
\]

\text{check for tachyons, runaways}

3 classical flat directions (pseudo-moduli)

Which are lifted by 1-loop Coleman-Weinberg potential

**SPECTRUM**

\[
\begin{array}{c}
\text{E} \\
\text{ee} \\
|hh| \quad \text{fields w/ tree-level masses} \\
|h\phi| \quad \text{fields w/ 1-loop masses} \\
0 \quad \text{massless Goldstones} + GSO \quad \text{Dirac} \\
\rightarrow \quad \text{no tachyonic directions; SUSY vacua are stable. (1-loop)}
\end{array}
\]

Aside: Komargodski-Sohn \( y_{\text{hm}} \)

\( \Rightarrow \) anomalously small gaugino mass

(\( y_{\text{hm}} \) relates gaugino mass to topology of base off pseudo-moduli space)
\(2\) MACRO MODEL II

Now we actually gauge \(SU(n)\)

\[ F > 3n \quad \implies \quad F < \frac{3}{2}n \quad \text{(Magnetic) is free glue.} \]

- **First thing to check: effect of D-terms on scalar potential**
  \[ V_0 = \frac{1}{2} g^2 \left( \text{Tr} \, Y^+ Y - \text{Tr} \, \tilde{Y}^+ \tilde{Y} \right)^2 \]
  
  **But** \( V_0 = 0 \) on vacuum of MACRO MODEL II.
  
  This previous vacuum remains a minimum of tree-level pot.

- **Superhiggs mechanism**
  - \(SU(n)\) gauge fields get mass \(g^2\)
  - Goldstone's eaten
  - Some pseudomoduli get mass \(g^2\)

- **Next calculate Coleman-Weinberg potential for pseudomoduli to check stability.**

**But:**

- Effect of \(SU(n)\) gauge fields drop out \(Q\) leading \(Q\)
  - D-terms vanish on vacuum manifold
  - Massive gauge fields do not couple to nonzero F-terms

**NET EFFECT OF GAUDED \(SU(n)\): SUSY VACUA RESTORED!**

\[ W_{\text{quark}} = (\text{det} \, \frac{\partial}{\partial \phi})^{1 \over 2} \]

- \(Y, \tilde{Y}\) get mass \(\langle h^\pm \rangle\)
  - Integrate out (scale matching)
  - \(\Phi\) is pure \(SU(n)\)

Introduce dynamical scale \(\Lambda\)

\[ \text{SUSY vac:} \quad \langle h^\pm \rangle = \Lambda \left( \frac{1}{\Lambda} \right)^{2n-1} \quad h_{\text{FxF}} = t \quad \left( \text{for } F > \frac{3}{2}n \right) \quad \Lambda_{\text{FxF}} \]

\[ \epsilon = \frac{1}{\Lambda^2}, \quad \text{small parameter}, \quad \epsilon \ll 1 \]

\[ |h^\pm| \ll |\langle h^\pm \rangle| \ll |\Lambda| \]

Well below Landau pole, low-E get justified

**Stability = metastable vacua**
DYNAMICAL SUSY RESTORATION

- $\Lambda \to \infty \text{ w/ } \mu \text{ fixed} : \text{ SUSY BREAKS SUSY (SUSY VAC \to \infty)}$
- $\Lambda \text{ large, finite} : \text{ SUSY VACUA COMES IN FROM } \infty$

EFFECTS FROM UV THEORY

EXPECT: DECOUPLING OF $\Lambda$-SCALE THY FROM $E \ll \Lambda$ EFT.

\[ V_{\text{th}} \text{ (for UV EFT)} \sim |\mu|^2 \]

NOT IR ANALYTIC IN $|\mu|^2$ PARAM OF $W$.

WHY? MODES WE INTEGRATED OUT BECOME HARMLESS AS $|\mu|^2 \to 0$.

ON THE OTHER HAND, CONTRIBUTION FROM MICRO THY MUST GO AS

\[ |\mu|^2 \left| \frac{\mu^2}{|\Lambda_m|^2} \right| = |\mu^2| \ll |\mu|^2 \]

THIS IS IR ANALYTIC ($|\mu|^2$ VS $|\mu|^2$) IN $\mu^2$, DIFFERENTIABLE $\approx 0$.

COMES FROM INTEGRATING OUT HEAVY MODES ($\sim \Lambda_m$).

CORRECTIONS $\sim |\mu^2| \to \text{ NEGLIGIBLE}$.

SHOW UP IN $8k$

$0$ NEUTRAL VAC IN SCD - ISS

LAST INGREDIENT: MAKE SUSY SUSY DYNAMICAL

ELECTRIC (UV) THEORY: $SU(N)$ SCD w/ Holomorphic Scale $\Lambda$, F QUARKS

$W = \text{Tr} MM$

$\mu \Lambda_m \approx \frac{\mu}{\Lambda}$

in degenerate (nondeg. discussed as deformation).

$M ; \ll |\mu|$

SEIBERG DUALITY: $SU(N) = SU(N) \text{ MAGNETIC} \Lambda \to \mu$ SCD $\Lambda$

F HAS QUARKS $c \vec{g}$ 1 F HIGGS $M$

$F \frac{N^2-1}{2N} \to \text{ IR FREE, SMOOTH K NEAR ORIGIN } \to K = \frac{1}{\Lambda} \text{Tr} \left( \hat{g} \hat{g} + \hat{g}^2 \right)$

$W_m = \frac{1}{\Lambda} \text{Tr} \hat{M} \hat{g} + \text{Tr} MM$

$\hat{g}^{\alpha + \beta + \gamma} \text{ is f.i. under-contravariant.}$

from scale matching of UV+IR theories.
This thing matches our warpo model II if

\[ \begin{align*}
\psi, \tilde{\psi} &= \tilde{\psi}, \\
\bar{\psi} &= \bar{\psi}, \\
\lambda &= \lambda, \\
\tilde{\lambda} &= \tilde{\lambda}.
\end{align*} \]

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\end{align*} \]

**Conclusion:** \( N/2 \leq F \leq \frac{3}{2} N \) with suitable tree masses has metastable SUSY ground state near origin.

- We established this in strongly coupled regime of UV theory.
- Vac param by 2 dillness' 15's 6, 6
- Result includes non-susy, non-chiral info.

**Lifetime of metastable vacuum:**

By using the "bounce action" of Coleman, \( S \sim \frac{1}{\epsilon \left( (F-3N)/(F-N) \right)} \)

\[ \begin{align*}
\langle \phi_{3N} \rangle &= 0, \\
\langle \phi_{3N} \rangle &= \frac{F}{N} \int_{(F-3N)/(F-N)} \Gamma F.
\end{align*} \]

SUSY & SUSY vacua are parametrically far apart

\( \epsilon \text{ param is } \epsilon \ll 1 \)

**Closing remarks**

- Can generalize to nondegenerate \( w \)
- Can generalize to diff range of \( F \)

Continuos

Hermetable vac has compact space of vacua (moduli space)

- Discrete space of susy vacua

\[ \Rightarrow \text{ early universe may prefer to populate metastable vac} \]