NON SUPERSYMMETRIC META–STABLE VACUA IN $\mathcal{N} = 1$ SQCD WITH ADJOINT MATTER

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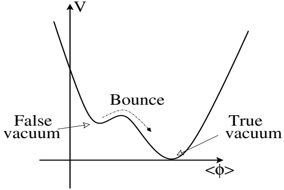
Outlines

- $\mathcal{N} = 1$ Supersymmetric gauge theories
  Witten Index $\neq 0 \Rightarrow$ Supersymmetric vacua

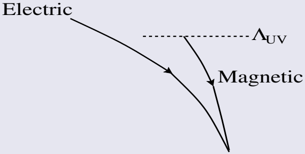
- *Non supersymmetric meta-stable states* $\Longrightarrow$



Non susy Meta–stable states in massive $\mathcal{N} = 1$ SQCD (ISS)

Intriligator, Seiberg, Shih: `hep-th/0602239`

- Seiberg Duality $\Rightarrow$ IR free magnetic description ($N_c + 1 < N_f \leq \frac{3}{2}N_c$)

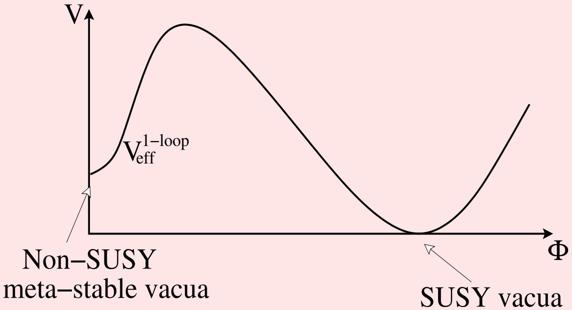


- In dual magnetic theory tree-level vacua with spontaneous breaking of supersymmetry via *O'Raifeartaigh mechanism*

THE ISS MODEL

- Small field region:
  - Perturbative corrections lift classical flat directions in tree-level susy breaking vacua ⇒ True quantum minimum
- Large field region
  - Recover supersymmetric vacua via non perturbative effects

SCALAR POTENTIAL



- *Lifetime* of metastable state estimated to be parametrically large

$SU(N_c)$ SQCD WITH ADJOINT

- IR Non-susy Meta-stable vacua are *generic* in $\mathcal{N}=1$ gauge theories?
- In model with more complicated Seiberg like duality?

- Extension of massive SQCD: add field X in *adjoint* representation of gauge group

	$SU(N_c)$	$SU(N_f)$	$SU(N_f)$
Q	N_c	N_f	1
$\tilde{Q}$	$\overline{N}_c$	1	$\overline{N}_f$
X	adj	1	1

$$W_{el} = \frac{g_X}{3}\mathrm{Tr}X^3 + \frac{m_X}{2}\mathrm{Tr}X^2 + \lambda_X \mathrm{Tr}X + \lambda_Q\,\mathrm{tr}QX\tilde{Q} + m_Q\,\mathrm{tr}Q\tilde{Q}$$

- Electric-Magnetic duality — Kutasov, Seiberg, Schwimmer: hep-th/9510222
  - More mesons: $M_1 = Q\tilde{Q}$ $\quad M_2 = QX\tilde{Q}$
  - More flat directions $\Longrightarrow$ *Instability ?*
- Add mesonic deformation: $W_{el} \rightarrow W_{el} + h\,\mathrm{tr}(Q\tilde{Q})^2$

$\Rightarrow$ *Prevents from dangerous extra flat directions*

Dual magnetic description $SU(2N_f - N_c = \tilde{N})$

- Dual magnetic *superpotential* with rescaled couplings

$$W_{magn} = \frac{g_Y}{3}\mathrm{Tr}Y^3 + \frac{m_Y}{2}\mathrm{Tr}Y^2 + \lambda_Y \mathrm{Tr}Y + tr(h_1 M_1 q\tilde{q} + h_2 M_2 q\tilde{q} + h_3 M_1 q Y \tilde{q})$$
$$-h_1 m_1^2\, trM_1 - h_2 m_2^2\, trM_2 + m_3\, trM_1^2$$

- *Scale matching relation*

$$\Lambda^{2N_c - N_f}\tilde{\Lambda}^{2\tilde{N} - N_f} = \left(\frac{\mu}{g_X}\right)^{2N_f}$$

	$SU(2N_f - N_c = \tilde{N})$	$SU(N_f)$	$SU(N_f)$
q	$2N_c - N_f$	N_f	1
$\tilde{q}$	$\overline{2N_c - N_f}$	1	$\overline{N}_f$
Y	adj	1	1
M_1	1	N_f	$\overline{N}_f$
M_2	1	N_f	$\overline{N}_f$

IR Free window: $\frac{N_c}{2} < N_f < \frac{2}{3}N_c$

- Solve F and D eqs but

Rank condition ($\tilde{N} < N_f$): $(c = 1, \ldots \tilde{N};\ \ i,j = 1 \ldots N_f)$

$$F_{M_2} = h_2 q_i^c \tilde{q}_{cj} - h_2 m_2^2 \delta_{ij} \neq 0 \quad \Rightarrow \quad \text{Supersymmetry breaking}$$

Non supersymmetric vacua

- Classical vacua

$$\langle q\rangle = \begin{pmatrix} m_2 e^{\theta}\,\mathbf{1}_{\tilde N} \\ 0 \end{pmatrix} \qquad \langle \tilde q^T\rangle = \begin{pmatrix} m_2 e^{-\theta}\,\mathbf{1}_{\tilde N} \\ 0 \end{pmatrix} \quad \langle Y\rangle = \begin{pmatrix} y_1\,\mathbf{1}_{n_1} & 0 \\ 0 & y_2\,\mathbf{1}_{\tilde N - n_1} \end{pmatrix}$$

$$\langle M_1\rangle = \begin{pmatrix} p_1^A\,\mathbf{1}_{\tilde N} & 0 \\ 0 & p_1^B\,\mathbf{1}_{N_f-\tilde N} \end{pmatrix} \qquad \langle M_2\rangle = \begin{pmatrix} p_2^A\,\mathbf{1}_{\tilde N} & 0 \\ 0 & \mathcal{X} \end{pmatrix}$$

- Non null scalar potential

$$V_{min} = |F_{M_2}|^2 = (N_f - \tilde N)|h_2 m_2^2|^2 = (N_c - N_f)|h_2 m_2^2|^2$$

- $\mathcal{X}, \theta$ PseudoGoldstones:
  Classical flat directions not related to broken symmetries
- Landscape of vacua at classical level parametrized by Y eigenvalues number $n_1 \in \mathbb{Z}_{\geq 0}$

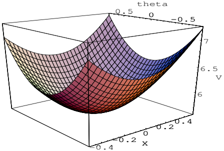
WHAT HAPPENS AT QUANTUM LEVEL?

1–LOOP QUANTUM CORRECTIONS

- Study fluctuations around classical vacua

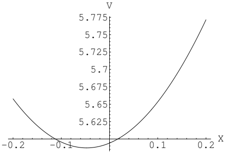
TWO SECTORS

- Supersymmetric one $\Rightarrow$ No contribution to the scalar potential
- Non supersymmetric one $\Rightarrow$ 1-loop quantum corrections
  - Model of pure chiral fields
  - Only F-contributions to effective potential



$\Leftarrow \; V^{1-loop}(\mathcal{X},\theta)$

$V^{1-loop}(\mathcal{X},\theta=0) \;\Rightarrow$



$\Rightarrow$ True quantum minimum!

- PseudoGoldstones $\mathcal{X},\theta$ get positive masses
- Minimum *not at the origin* of $\mathcal{X}$
- Landscape of classical vacua wiped out by quantum corrections
  Lower energy $\langle Y\rangle = 0$

Is this vacuum long living?

SUPERSYMMETRIC VACUA

- Large field region $\Rightarrow$ Restoration of supersymmetry via non perturbative effects (Gaugino condensation)

$$\Downarrow$$

Meta–stability of the non supersymmetric vacuum

- Supersymmetric vacuum $\left(\epsilon = \frac{m_2}{\tilde{\Lambda}} \quad \xi = \frac{m_2}{m_Y}\right)$

$$\langle q \rangle = 0 \qquad \langle \tilde{q} \rangle = 0 \qquad \langle Y \rangle = 0 \qquad \langle M_1 \rangle = \frac{h_1 m_1^2}{2 m_3} \mathbf{1}_{N_f}$$

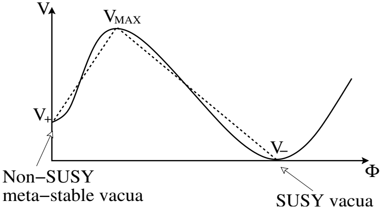
$$\langle h_2 M_2 \rangle = \tilde{\Lambda} \epsilon^{\frac{\tilde{N}}{N_f - \tilde{N}}} \xi^{\frac{\tilde{N}}{N_f - \tilde{N}}} \mathbf{1}_{N_f} = m_2 \left(\frac{1}{\epsilon}\right)^{\frac{N_f - 2\tilde{N}}{N_f - \tilde{N}}} \xi^{\frac{\tilde{N}}{N_f - \tilde{N}}} \mathbf{1}_{N_f}$$

- Far from Non-susy Meta-stable State *and* from Landau Pole

$$m_2 \ll \langle h_2 M_2 \rangle \ll \tilde{\Lambda}$$

LIFETIME OF THE META–STABLE VACUUM

- *Decay probability* of the metastable state $\Gamma \sim e^{-S_{bounce}}$



- S_{bounce}: Difference in the action between false and true vacuum ($\epsilon = \frac{m_2}{\tilde{\Lambda}}$)

$$S_{bounce} \sim \left(\left(\frac{1}{\epsilon}\right)^{\frac{N_f - 2\tilde{N}}{N_f - \tilde{N}}} \xi^{\frac{\tilde{N}}{N_f - \tilde{N}}} \right)^4 \sim \left(\frac{1}{\epsilon}\right)^{4\frac{N_f - 2\tilde{N}}{N_f - \tilde{N}}} ;$$

- In *IR free* magnetic window: $\frac{N_c}{2} < N_f < \frac{2}{3} N_c \qquad (\tilde{N} = 2N_f - N_c)$

$$4\frac{N_f - 2\tilde{N}}{N_f - \tilde{N}} > 0 \qquad \Rightarrow \qquad \epsilon \to 0, \qquad S_{bounce} \gg 1$$

- Lifetime of meta–stable non supersymmetric vacuum can be made parametrically large

CONCLUSIONS

- Exist Meta–stable non supersymmetric vacua in SQCD with *adjoint*
  - Classical landscape wiped out by quantum corrections
  - PseudoGoldstones stabilized by quantum corrections
  - Lifetime controlled by dimensionless ratio ϵ
  - Mesonic deformations necessary to avoid extra flat directions

- Meta-stability seems generic in $\mathcal{N} = 1$ gauge theories

  Franco,Uranga: hep-th/0604136; Ooguri,Ookouchi: hep-th/0606061.

- D-branes realization in string theory

  Franco,Garcia-Etxebarria,Uranga: hep-th/0607218; Ooguri,Ookouchi: hep-th/0607183; Ahn: hep-th/0608160

MESONIC DEFORMATIONS; KAHLER POTENTIAL

- Mesonic deformations

$$W_{el} \rightarrow W_{el} + \Delta W_{el} \qquad \Delta W_{el} = \lambda_Q\, trQX\tilde{Q} + m_Q\, trQ\tilde{Q} + h\, tr(Q\tilde{Q})^2$$

- Quartic term from an integrated out second massive adjoint field Z

$$W_Z = m_Z \mathrm{Tr} Z^2 + \mathrm{Tr}\, ZQ\tilde{Q}$$

  - Scale matching relation

$$\Lambda_{2A}^{N_c - N_f} = \Lambda_{1A}^{2N_c - N_f} m_Z^{-N_c}$$

  - Full theory asymptotically free for $N_f < N_c$

- Condition on masses of the theory $\Lambda_{2A} \gg m_Q, m_X$

$$\Rightarrow \frac{m_Q m_Z}{\Lambda_{1A}^2} \ll 1 \qquad \frac{m_X m_Z}{\Lambda_{1A}^2} \ll 1$$

- Canonical Kahler potential

$$K = \frac{1}{\alpha_1^2 \Lambda^2} trM_1^\dagger M_1 + \frac{1}{\alpha_2^2 \Lambda^4} trM_2^\dagger M_2 + \frac{1}{\beta^2} \mathrm{Tr} Y^\dagger Y + \frac{1}{\gamma^2} (trq^\dagger q + tr\tilde{q}^\dagger \tilde{q})$$

Non supersymmetric vacuum: detail

- Rescaled couplings

$$h_1 = -\frac{\tilde{m}_Y}{2\mu^2}(\alpha_1\Lambda)\gamma^2 \qquad h_2 = -\frac{\tilde{g}_Y}{\mu^2}\left(\alpha_2\Lambda^2\right)\gamma^2 \qquad h_3 = -\frac{\tilde{g}_Y}{\mu^2}(\alpha_1\Lambda)\gamma^2\beta$$

$$h_1 m_1^2 = -m_Q\,\alpha_1\,\Lambda \qquad h_2 m_2^2 = -\lambda_Q\,\alpha_2\,\Lambda^2 \qquad m_3 = h(\alpha_1\Lambda)^2$$

- Non supersymmetric vacua

$$q = \begin{pmatrix} m_2 e^{\theta}\,\mathbf{1}_{\tilde{N}} \\ 0 \end{pmatrix} \qquad \tilde{q}^T = \begin{pmatrix} m_2 e^{-\theta}\,\mathbf{1}_{\tilde{N}} \\ 0 \end{pmatrix}$$

$$\langle M_1 \rangle = \begin{pmatrix} \frac{h_1}{2m_3}(m_1^2 - m_2^2)\,\mathbf{1}_{\tilde{N}} & 0 \\ 0 & \frac{h_1 m_1^2}{2m_3}\,\mathbf{1}_{N_f-\tilde{N}} \end{pmatrix} = \begin{pmatrix} p_1^A & 0 \\ 0 & p_1^B \end{pmatrix}$$

$$\langle M_2 \rangle = \begin{pmatrix} -\frac{h_1^2}{2h_2 m_3}(m_1^2 - m_2^2)\,\mathbf{1}_{\tilde{N}} & 0 \\ 0 & \mathcal{X} \end{pmatrix} = \begin{pmatrix} p_2^A & 0 \\ 0 & \mathcal{X} \end{pmatrix}$$

$$\langle Y \rangle = \begin{pmatrix} y_1 \mathbf{1}_{n_1} & 0 \\ 0 & y_2 \mathbf{1}_{\tilde{N}-n_1} \end{pmatrix} \qquad y_1 = -\frac{m_Y - \frac{h_3^2 m_2^4}{2m_3}}{g_Y}\,\frac{n_2}{n_1 - n_2} \qquad y_2 = \frac{m_Y - \frac{h_3^2 m_2^4}{2m_3}}{g_Y}\,\frac{n_1}{n_1 - n_2}$$

$$\lambda_Y = \frac{h_3 h_1 m_2^2}{2m_3}\left(m_2^2 - m_1^2\right) - \frac{m_Y^2}{g_Y}\left(1 - \frac{h_3^2 m_2^4}{2m_3 m_Y}\right)^2 \frac{n_1 n_2}{(n_1 - n_2)^2}$$

1-LOOP CORRECTIONS: DETAILS

- No D-terms corrections to the scalar potential
  - Vector multiplet do not contribute since vacuum satisfies D-equations
  - Contributions only from fields coupled to supersymmetry breaking sector
  - Charged fields coupled to supersymmetry breaking sector have zero vevs
    $\Rightarrow$ No D-contributions from charged fields
- $\Rightarrow$ Only F-term contributions with superpotential

$$q = \begin{pmatrix} ke^{\theta} + \xi_1 \\ \phi_1 \end{pmatrix} \qquad \tilde{q}^T = \begin{pmatrix} ke^{-\theta} + \xi_2 \\ \phi_2 \end{pmatrix} \qquad Y = \delta Y$$

$$M_1 = \begin{pmatrix} p_1^A + \xi_3 & \phi_3 \\ \phi_4 & p_1^B + \xi_4 \end{pmatrix} \qquad M_2 = \begin{pmatrix} p_2^A + \xi_5 & \phi_5 \\ \phi_6 & \mathcal{X} \end{pmatrix}$$

$$\begin{aligned} W_{fluct} \;&=\; h_2\left(\mathcal{X}\phi_1\phi_2 - m_2^2\mathcal{X}\right) + h_2 m_2\left(e^{\theta}\phi_2\phi_5 + e^{-\theta}\phi_1\phi_6\right) + \\ &\quad + h_1 m_2\left(e^{\theta}\phi_2\phi_3 + e^{-\theta}\phi_1\phi_4\right) + 2m_3\phi_3\phi_4 + \frac{h_1^2 m_1^2}{2m_3}\phi_1\phi_2 \end{aligned}$$

- Standard expressions for 1-loop quantum corrections to the scalar potential

$$V_{1-loop} = \frac{1}{64\pi^2} \mathrm{STr}\mathcal{M}^4 \log\frac{\mathcal{M}^2}{\Lambda^2} = \frac{1}{64\pi^2}\sum\left(m_B^4 \log\frac{m_B^2}{\Lambda^2} - m_F^4\log\frac{m_F^2}{\Lambda^2}\right)$$

$$m_B^2 = \begin{pmatrix} W^{\dagger ac}W_{cb} & W^{\dagger abc}W_c \\ W_{abc}W^{\dagger c} & W_{ac}W^{\dagger cb} \end{pmatrix} \qquad m_f^2 = \begin{pmatrix} W^{\dagger ac}W_{cb} & 0 \\ 0 & W_{ac}W^{\dagger cb} \end{pmatrix}$$