Dynamical SUSY Breaking in SQCD:

25 Years Later

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Phenomenological motivations & implications

Field theoretic aspects

- Pure SUSY YM
- SUSY QCD
- Vector-like SUSY Breaking
- Radiative SUSY Breaking
- Conformal SUSY Breaking

SUSY breaking

Tree-level / Non-renormalization

Radiative / Perturbative

Dynamical / Non-perturbative

Pure SYM $SU(N_C)$

$$\mathcal{W}_\alpha \mathcal{W}^\alpha = \lambda_\alpha \lambda^\alpha + \theta^2 F_{\mu\nu} F^{\mu\nu}$$

Witten index Z_{2N_C}/Z_2

gaugino condensation

$$\langle \lambda_\alpha \lambda^\alpha \rangle = \Lambda_L^3$$

$$U(1)_R \to Z_{2N_C} \to Z_2$$

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Massive SQCD $r = N_F/N_C$

$$\Lambda_L^3 = m^r \Lambda_H^{3-r}$$

Konishi anomaly equation

$$\bar{D}^2(Q^* e^{\mathcal{V}} Q) = m Q\tilde{Q} + \mathcal{W}_\alpha \mathcal{W}^\alpha$$

$$\langle Q\tilde{Q} \rangle = m^{r-1} \Lambda_H^{3-r}$$

Massless limit

$N_F < N_C$: $\langle Q\tilde{Q} \rangle \to \infty$
$N_F > N_C$: $\langle Q\tilde{Q} \rangle \to 0$

Witten index argument

classical flat direction Φ at large vev
1) broken gauge interaction:
   weak due to asymptotic freedom
2) unbroken gauge interaction:
   Φ interaction suppressed by the vev

Affleck, Dine, Seiberg: NP B256 (1985) 557

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$$W = S_{ij} Q^i \tilde{Q}^j \quad \Rightarrow \quad \langle Q^i \tilde{Q}^j \rangle = 0$$

$$W' = W + m_{ij} Q^i \tilde{Q}^j = S'_{ij} Q^i \tilde{Q}^j$$

$$K = |S_{ij}|^2 \sim |S'_{ij}|^2$$

Chiral

Vector-like: **semi-chiral**

non-chiral

e.g. $N_F = N_C = 2$

$$W = S_{ij} Q^i Q^j$$

Izawa, Yanagida: hep-th/9602180
Intriligator, Thomas: hep-th/9603158

$N_F > N_C$: $\langle Q^i \tilde{Q}^j \rangle = \langle S_{ij} \rangle = 0$

$W = S_{ij} Q^i \tilde{Q}^j$

cf. $\langle Q\tilde{Q} \rangle = m^{r-1} \Lambda_H^{3-r}$

$N_F < N_C$**?**

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$$W = \lambda S Q^i \tilde{Q}_i$$

$$W_{\text{eff}} = \Lambda_L^3 = (\lambda S)^r \Lambda_H^{3-r}$$

“ $V \propto \left| S^{r-1} \right|^2$ ” $r = N_F/N_C$

$$K_{\rm eff} \simeq \left(1 - \frac{N_C N_F |\lambda|^2}{16\pi^2} \ln \left|\frac{S}{eM}\right|^2\right) |S|^2$$

$$V \propto \left(\frac{\partial^2 K_{\rm eff}}{\partial S \partial S^*}\right)^{-1} \left|S^{r-1}\right|^2$$
$$\propto \left(1 + \frac{N_C N_F |\lambda|^2}{16\pi^2} \ln \left|\frac{S}{M}\right|^2\right) \left|S^{r-1}\right|^2$$

$$\frac{\partial V}{\partial |S|} \propto \frac{N_C N_F |\lambda|^2}{16\pi^2} - 1 + \frac{N_F}{N_C}$$

Izawa, Takahashi, Yanagida, Yonekura: 0902.3854 [hep-th]

$$\ln \frac{\partial^2 K_{\text{eff}}}{\partial S \partial S^*} = \int_{\mu=|S|}^{M} \tilde{\gamma}_S(\mu)\, d(\ln \mu)$$

Coleman, Weinberg: PR D7 (1973) 1888

$$V \propto \left|S^{r-1}\right|^2 \exp \int_{\mu=M}^{|S|} \tilde{\gamma}_S(\mu)\, d(\ln \mu)$$

$$\frac{\partial V}{\partial |S|} \propto \frac{1}{2}\tilde{\gamma}_S(|S|) - 1 + \frac{N_F}{N_C}$$

$$\tilde{\gamma}_S \simeq \frac{N_C N_F |\lambda|^2}{8\pi^2}$$

$$M\frac{\partial}{\partial M}|\lambda|^2 \simeq \frac{N_C N_F + 2}{8\pi^2}|\lambda|^4$$

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UV completion

$W = \lambda S Q^i \tilde{Q}_i + m P^a \tilde{P}_a$

$m = 0$, $\lambda = \lambda_*$: **CFT**

for $\frac{3}{2} N_C < N_F + N'_F < 3 N_C$

$$W_{\mathsf{eff}} = m^{r'}(\lambda S)^r \Lambda_H^{3-r-r'}$$

$$r = N_F/N_C \qquad r' = N'_F/N_C$$

mass-independent scheme

$$K_{\mathrm{eff}}^{\mathrm{conf}} \propto M^{\tilde{\gamma}_{S*}} |S|^{2-\tilde{\gamma}_{S*}}$$

$$\ln \frac{\partial^2 K_{\mathrm{eff}}^{\mathrm{conf}}}{\partial S \partial S^*} = \int_{\mu=|S|}^{M} \tilde{\gamma}_S(\mu)\, d(\ln \mu)$$

As $m \to 0$

$N_F' < N_C$**:** $|P\tilde{P}| \to \infty$

$N_F' > N_C$**:** $|P\tilde{P}| \to 0$

$$K_{\text{eff}}^{\text{mass}} = |\widehat{S}|^2 f\left(|\widehat{m}/\widehat{S}|\right)$$

$$\widehat{S} = M^{\tilde{\gamma}_{S*}/2} S^{1-\tilde{\gamma}_{S*}/2}$$

$$\widehat{m} = (M^{-\gamma_P} m)^{1/(1-\gamma_P)}$$

$$K_{\text{eff}} \simeq K_{\text{eff}}^{\text{conf}} \quad \textbf{for} \quad |S| \to \infty$$

$$V \propto |S|^{2\left(\frac{1}{2}\gamma_{S*}-1+\frac{N_F}{N_C}\right)}$$

Izawa, Takahashi, Yanagida, Yonekura: to appear

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