D-term Dynamical SUSY Breaking

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Plan

- Introduction
- General Discussion
- Gap equation
- Some Comments on Phenomenological Application
- Summary

Introduction

SUPERSYMMETRY

is one of the attractive scenarios
solving the hierarchy problem,
but it must be broken at low energy

Dynamical SUSY breaking(DSB)
is most desirable to solve
the hierarchy problem

F-term DSB is induced by non-perturbative effects
due to nonrenormalization theorem
and well studied so far

D-term SUSY breaking is NOT affected
by the nonrenormalization theorem

In principle, D-term DSB is possible,
but no known explicit model as far as we know

In this talk, we will accomplish

D-term DSB (DDSB)

in a self-consistent

Hartree-Fock approximation

General Discussion

N=1 SUSY U(N) gauge theory with an adjoint chiral multiplet

$$\mathcal{L} = \int d^4\theta K\left(\Phi^a, \bar{\Phi}^a, V\right) + \int d^2\theta \, \mathrm{Im} \frac{1}{2} \tau_{ab}\left(\Phi^a\right) \mathcal{W}^{a\alpha} \mathcal{W}^b_\alpha + \left[\int d^2\theta W\left(\Phi^a\right) + h.c. \right]$$

$$\mathcal{W}^a_\alpha = -i\lambda^a_\alpha(y) + \left[\delta_\alpha^\beta D^a(y) - \frac{i}{2}\left(\sigma^\mu \bar{\sigma}^\nu\right)_\alpha^\beta F^a_{\mu\nu}(y) \right] \theta_\beta$$

$$\Phi^a = \phi^a(y) + \sqrt{2}\theta\psi^a(y) + \theta\theta F^a(y) \quad y^\mu = x^\mu + i\theta\sigma^\mu\bar{\theta}$$

N=2→N=1 partial breaking models naturally applicable

Antoniadis, Partrouche & Taylor (1996); Fujiwara, Itoyama & Sakaguchi (2005)

Fermion masses

Important
D=5 operator

$$\int d^2\theta \tau_{ab}(\Phi) \mathcal{W}^{a\alpha} \mathcal{W}^b_\alpha \supset \tau_{abc}(\Phi) \psi^c \lambda^a D^b + \tau_{abc}(\Phi) F^c \lambda^a \lambda^b$$

Dirac mass term

$$\int d^2\theta W(\Phi) \supset -\frac{1}{2} \partial_a \partial_b W(\Phi) \psi^a \psi^b$$

$$\tau_{abc} \equiv \partial \tau_{ab}(\Phi) / \partial \phi^c$$

Fermion mass terms

Mixed Majorana-Dirac type masses (<F>=0 assumed)

$$-\frac{1}{2}\begin{pmatrix}\lambda^a & \psi^a\end{pmatrix}\begin{pmatrix}0 & -\frac{\sqrt{2}}{4}\tau_{abc}D^b \\ -\frac{\sqrt{2}}{4}\tau_{abc}D^b & \partial_a\partial_c W\end{pmatrix}\begin{pmatrix}\lambda^c \\ \psi^c\end{pmatrix}+h.c.$$

Mass matrix ⇒

$$M_F \equiv \begin{pmatrix}0 & -\frac{\sqrt{2}}{4}\left\langle\tau_{0aa}D^0\right\rangle \\ -\frac{\sqrt{2}}{4}\left\langle\tau_{0aa}D^0\right\rangle & \left\langle\partial_a\partial_a W\right\rangle\end{pmatrix}$$

if $\langle D \rangle \neq 0 \;\&\; \langle \partial_a \partial_a W \rangle \neq 0$

$$m_{\pm} = \frac{1}{2}\langle \partial_a \partial_a W \rangle \left[1 \pm \sqrt{1 + \left(\frac{2\langle D \rangle}{\langle \partial_a \partial_a W \rangle} \right)^2} \right]$$

$$D \equiv -\frac{\sqrt{2}}{4}\tau_{0aa} D^0$$

Gaugino becomes massive
by nonzero <D>

$\Rightarrow$ SUSY is broken

D-term equation of motion:

$$\left\langle D^{0}\right\rangle = -\frac{1}{2\sqrt{2}}\left\langle g^{00}\left(\tau_{0cd}\psi^{d}\lambda^{c}+\bar{\tau}_{0cd}\bar{\psi}^{d}\bar{\lambda}^{c}\right)\right\rangle$$

Dirac bilinears condensation

The value of ‹D› will be determined by the gap equation

Gap equation

1-loop effective potential for D-term

Tree level D-term pot. + 1-loop CW pot.
+ counter term ($\Lambda/2\, W^\alpha W_\alpha$)

$$V^{(D)}_{1-loop} = \sum_a |m_a|^4 \left\{ \left(c + \frac{1}{64\pi^2} \right) \Delta^2 + \Lambda'_{res} \frac{\Delta^4}{8} - \frac{1}{32\pi^2} \left[\lambda^{(+)4} \log \lambda^{(+)2} + \lambda^{(-)4} \log \lambda^{(-)2} \right] \right\}$$

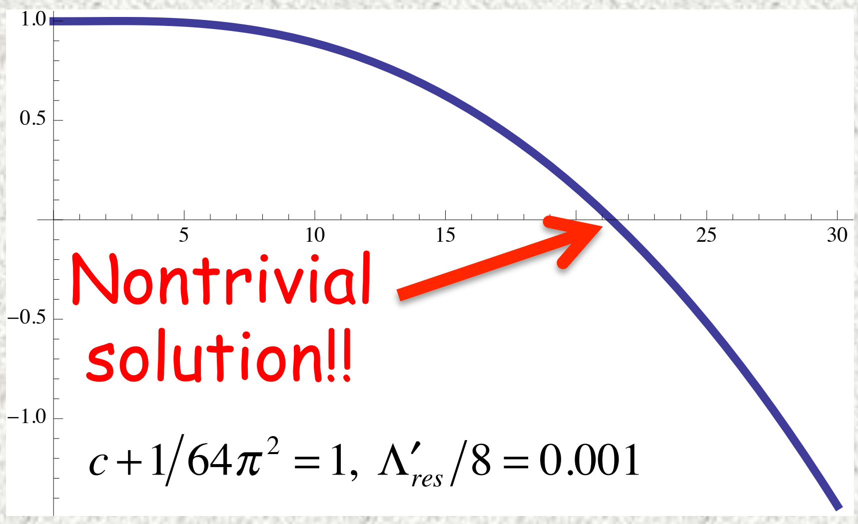
$$m_a \equiv \langle \partial_a \partial_a W \rangle,\ \lambda^{(\pm)} \equiv \frac{1}{2}\left[1 \pm \sqrt{1+\Delta^2} \right],\ \Delta \equiv \frac{\langle \tau_{0aa} D \rangle}{\sqrt{2} m_a},\ \Lambda'_{res} \equiv c + \beta + \Lambda_{res} + \frac{1}{64\pi^2},$$

$$\frac{1}{\sum_a |m_a|^4} \left. \frac{\partial^2 V}{(\partial\Delta)^2} \right|_{\Delta=0} = 2c,\ \beta \equiv \frac{\langle g_{00} \rangle |\langle \partial_a \partial_a W \rangle|^2}{\sum_a |m_a|^4 |\langle \tau_{0aa} \rangle|^2},\quad \Lambda_{res} \equiv \frac{(\mathrm{Im}\,\Lambda) |\langle \partial_a \partial_a W \rangle|^2}{\sum_a |m_a|^4 |\langle \tau_{0aa} \rangle|^2}$$

Gap equation

$$0 = \frac{\partial V^{(D)}_{1-loop}}{\partial \Delta} = \Delta\left[c + \frac{1}{64\pi^2} + \frac{\Lambda'_{res}}{4}\Delta^2 - \frac{1}{64\pi^2\sqrt{1+\Delta^2}}\left\{ \lambda^{(+)3}\left(2\log\lambda^{(+)2}+1\right) - \lambda^{(-)3}\left(2\log\lambda^{(-)2}+1\right)\right\}\right]$$

$$\frac{1}{\Delta}\frac{\partial V^{(D)}_{1\text{-loop}}}{\partial \Delta}$$

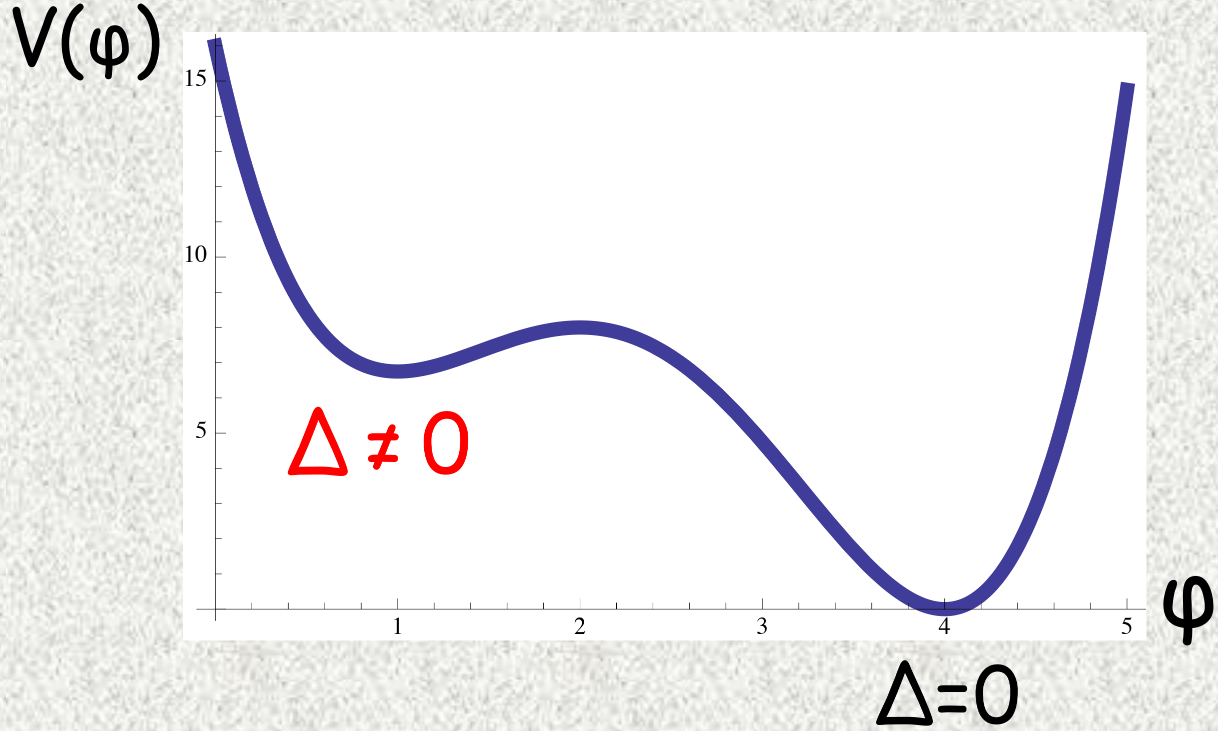


Δ

$E = D^2/2 \geqq 0$ in SUSY

⇒ Trivial solution $\Delta=0$ is NOT lifted

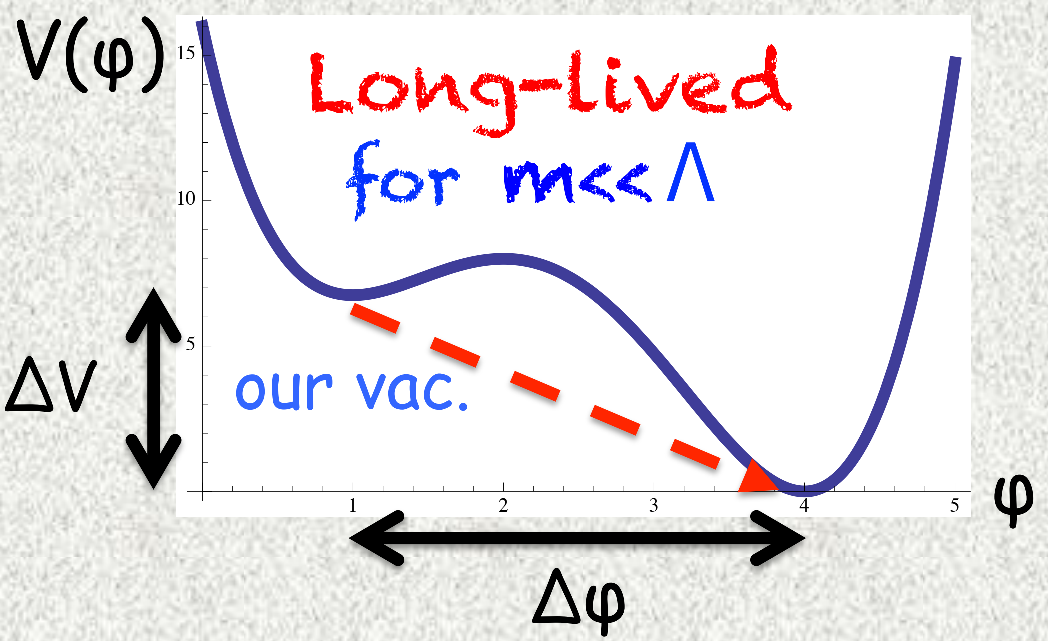
⇒ Our SUSY breaking vac. is a local min.



Metastability of our false vacuum

<D> = 0 tree vacuum is not lifted

⇒ check if our vacuum <D> ≠ 0 is sufficiently long-lived



Coleman & De Luccia(1980)

Decay rate of the false vacuum

$$\propto \exp\left[-\frac{\langle \Delta\phi \rangle^4}{\langle \Delta V \rangle}\right] \approx \exp\left[-\frac{\Lambda^2}{m^2}\right] \ll 1$$

m: mass of Φ, Λ: cutoff scale

Some Comments on Phenomenological Application

Following the model of Fox, Nelson & Weiner (2002),

consider a N=2 gauge sector & N=1 matter sector in MSSM

↑

Chirality, Asymptotic freedom

Take the gauge group $G' \times G_{SM}$ (G':hidden gauge group)

D=5 gauge kinetic term

provides Dirac gaugino mass term

$$\int d^2\theta \tau_{abc}(\Phi)\Phi^c_{SM}\mathcal{W}'^{\alpha a}\mathcal{W}^b_{\alpha SM} \Rightarrow \tau_{abc}(\langle\Phi\rangle)\langle D'^a\rangle \psi^c_{SM}\lambda^b_{SM}$$

Gaugino masses are generated

at tree level

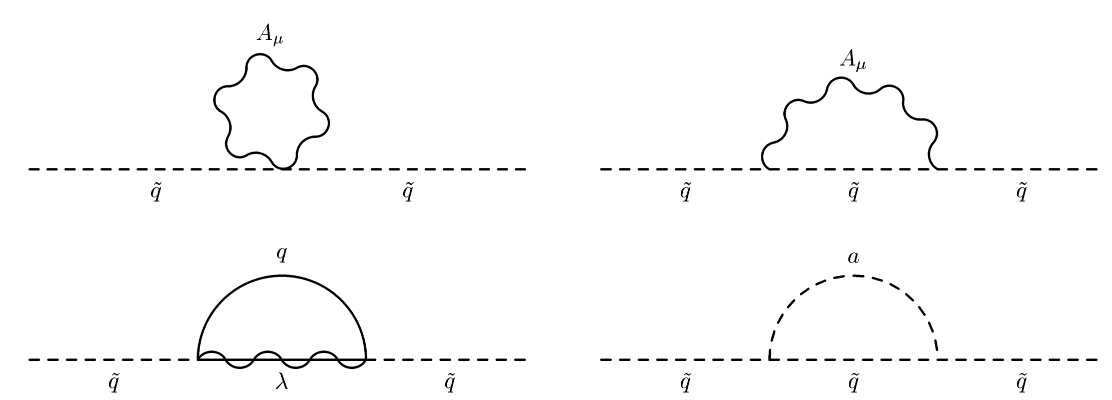
Once gaugino masses are generated at tree level,

sfermion masses are generated by RGE effects

Sfermion masses @1-loop

$$M_{sf}^2 \approx \frac{C_i(R)\alpha_i}{\pi} M_{\lambda_i}^2 \log\left[\frac{m_a^2}{M_{\lambda_i}^2}\right]$$

(i = $SU(3)_C$, $SU(2)_L$, $U(1)_Y$)



Fox, Nelson & Weiner, JHEP08 (2002) 035

Flavor blind ⇒ No SUSY flavor & CP problems

Summary

- A new dynamical mechanism of DDSB proposed
- Shown a nontrivial solution of the gap eq. with nonzero <D> in a self-consistent Hartree-Fock approx.
- Our vacuum is metastable & can be made long-lived
- Phenomenological Application briefly discussed

Thank you very much for your attention!!