R-symmetry, supersymmetry breaking and metastable vacua in supergravity [1]

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Abstract

We study the relations among R-symmetry, supersymmetry breaking and metastability in $N = 1$ supergravity with a continuous global $U(1)_R$ symmetry. First we show that the general argument by Nelson and Seiberg (NS) for dynamical supersymmetry (SUSY) breaking still holds with local SUSY, except for a certain nontrivial case. Then, we discuss the relation between explicit R-symmetry breaking terms and the metastabilities of SUSY breaking vacua in O'Raifeartaigh model. We show that the R-breaking terms are basically divided into two categories. One of them generates SUSY solutions which disappear if we uplift the original SUSY breaking minimum to a Minkowski vacuum. In such sense, not all of the explicit R-breaking terms leads to a metastability of the SUSY breaking vacuum.

1 Introduction

Supersymmetric extensions of the standard model are promising candidate for the physics around TeV scale and have some special features : stabilizing the huge hierarchy between the weak scale and the Planck scale, and so on. However, the supersymmetry must be broken with certain amount of the gaugino and scalar masses in our real world. The dynamical supersymmetry breaking has a big predictability of the structure of such supersymmetric particles. It was shown by Nelson and Seiberg [2] that a global $U(1)_R$ symmetry is necessary for a spontaneous F-term supersymmetry breaking at the ground state of generic models with a global supersymmetry. This predicts an appearance of massless Goldstone boson, R-axion, in models with a dynamical supersymmetry breaking with nonvanishing Majorana gaugino masses which breaks $U(1)_R$ symmetry. Recently, Intriligator, Seiberg and Shih suggest (ISS) [3, 4] that the supersymmetry breaking vacuum we are living can be metastable for avoiding the R-axion in O'Raifeartaigh(OR) model. They add explicit R-symmetry breaking term, whose magnitude is denoted by ϵ, to R-symmetric OR Model to avoid R-axion. The R-symmetry breaking terms would not affect the original SUSY breaking minimum if they are tiny(ϵ is enough small). However, they can lead to a supersymmetric minimum newly. The distance between the orinal SUSY breaking vacuum and the new supersymmetric vacua would be estimated by $O(1/\epsilon)$ in the field space. Thus if R-symmetry breaking terms are sufficiently small, the original SUSY breaking vacuum would be long-lived and metastable.

On the other hand, the global SUSY model always has positive vacuum energy at the SUSY breaking minimum. Therefore, supergravity effects should be also considered to realize the almost vanishing vacuum energy. Besides in the above global SUSY model with metastable SUSY breaking vacuum, some fields have large vacuum values at the supersymmetric vacua. In such case, supergravity effects might be sizeable.

In this talk, we reconsider the above argument for the dynamical supersymmetry breaking and its metastability within the framework of supergravity. Actually we find the special condition about Kahler potential that R-symmetry breaking is sufficient for dynamical SUSY

[1]This talk is based on the paper [1] collaborated with T. Kobayashi and H. Abe.

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breaking in supergravity. Besides we find out the relation between R-symmetry and SUSY breaking in R-symmetric OR model, and we suggest explicit R-symmetry breaking terms also lead the metastability of SUSY breaking vacuum under a certain condition about Kahler potential in local SUSY. However, an R-symmetry breaking term must be tuned to realize the almost vanishing vacuum energy. For that reason, the R-symmetry breaking terms have to be sizeable, and that would affect vacuum structure such as the metastability. Therefore, we classify the explicit R-symmetry breaking terms and show that the R-breaking terms are basically divided into two categories. One of them generates SUSY solutions which disappear if we uplift the original SUSY breaking minimum to a Minkowski vacuum. In such sense, we suggest that not all of the explicit R-breaking terms leads to a metastability of the SUSY breaking vacuum. We show these discussions more concretely in the next sections.

2 Nelson-Seiberg argument in supergravity

We study the Nelson-Seiberg argument within the framework of supergravity. Let us consider the SUSY model with chiral superfields $z_i(i=1\cdots n)$ and superpotential $W(z_i)$. The $U(1)_R$ charge of z_i is q_i. Suppose that the n-th component z_n is nozero and $q_n \neq 0$.

$$W=(z_n)^{\frac{2}{q_n}}f(x_1\cdots x_{n-1}), \tag{1}$$

where $x_i=\frac{z_i}{(z_n)^{(\frac{q_i}{q_n})}}$. In supergravity F-flat conditions are $D_IW=W_I+K_IW=0$, where Planck scale is set to unit. Especially, concerned with z_n, we obtain

$$D_{z_n}W=(\frac{2}{q_n}+z_nK_{z_n})z_n^{\frac{2}{q_n}-1}f=0. \tag{2}$$

If $\frac{2}{q_n}+z_nK_{z_n}\neq 0$, we obtain $f=0$. Then, putting $D_{x_i}W=0$ together, we find $f_{x_i}=f=0$. These are n complex equations with $n-1$ unknowns , so these are no solutions generally. For example, in the model that R-charges of all superfields are positive and Kahler metric is canonical, R-symmetry breaking is sufficient condition for SUSY breaking. (We find the exception of NS. See [1].)

3 the metastability of SUSY breaking vacuum in supergravity

We discuss the relation between the metastability and explicit R-symmetry breaking in OR model.

3.1 Generalized OR Model

In Generalized OR Model [4], the superpotential is

$$W_{OR}=\sum_{a=1}^{n}X_a g_a(\phi_i), \tag{3}$$

where $R[X_a]=2,\ R[\phi_i]=0,\ i=1\cdots s$, and $g_a(\phi_i)$ are generic functions. n is set to $n>s$. In global SUSY, SUSY is always broken because F-flat conditions $\partial_{X_a}W_{OR}=g_a=0$ are n-equations for $s(<n)$ unknows. On the other hand, in supergravity, F-flat conditions of X_a are

$$D_{X_a}W_{OR} = M_{ab}g_b(\phi_i) \qquad (M_{ab} = \delta_{ab} + K_{X_a}X_b). \tag{4}$$

If $det(M) = 1+\sum_a K_{X_a}X_a \neq 0$, these mean $g_a = 0$. For example, if Kahler metric is canonical, SUSY is always broken. In this case, we find $V > 0$. This means SUSY breaking vacua always have positive vacuum energy in OR model.

3.2 Explicit R-symmetry breaking in supergravity

R-symmetry should be broken explicitly not only to avoid R-axion but also to make Mikowski vacuum if Kahler metric is canonical. Explicit R-symmetry breaking terms are

$$W_{\not R} = W_{\not R}^{(A)} + W_{\not R}^{(B)}, \tag{5}$$

where

$$W_{\not R}^{(A)}(X_{a\neq 1};\phi_i) = c(\phi_i) + \frac{1}{2}\sum_{a,b\neq 1} m\,\epsilon_{ab}(\phi_i)X_aX_b + \cdots , \tag{6}$$

$$W_{\not R}^{(B)}(X_1; X_{a\neq 1},\phi_i) = \sum_{a\neq 1} m\,\epsilon_{a1}(\phi_i)X_aX_1 + \frac{1}{2}m\,\epsilon_{11}(\phi_i)X_1^2 + \cdots . \tag{7}$$

Superpotential W_{OR} is written as $W_{OR} = fX_1 + \sum_a X_a g_a(\phi_i)$ by changing the base of X_a, where all of $g_a(\phi_i)$ satisfy $g_a(0) = 0$. If $W = W_{OR} + W_{\not R}$, the solutions which satisfy the F-flat conditions could appear generally. They depend on $W_{\not R}$ as the argument in global SUSY. However, the size of $W_{\not R}$ must be tuned to set the vacuum energy to almost zero. This uplift causes the disappears of the supersymmetric vacua.

We set SUSY breaking vacuum with $V = 0$ to the point in the slice, $X_{a\neq 1} = \phi_i = 0$. In the model that $W = W_{OR} + W_{\not R}^{(A)}$, we discuss that the SUSY breaking vacuum would be stable. On the other hand, in the model that $W = W_{OR} + W_{\not R}$, the SUSY breaking vacuum is metastable or unstable. The stability of the vacuum is estimated by ϵ. If ϵ is tiny, the SUSY breaking vacuum with $V = 0$ becomes long-lived.

4 Summary

First we discuss that global $U(1)_R$ symmetry breaking is sufficient condition for SUSY breaking in supergravity where the Kahler potential satisfies $\frac{2}{q_n} + z_nK_{z_n} \neq 0$. Then we discuss the metastability in explicit R-symmetry breaking OR model. Generally explicit R-symmetry breaking causes metastable SUSY breaking vacua in supergravity, but we find the superpotential which makes the SUSY breaking vacuum with $V = 0$ stable.

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References

[1] H. Abe, T. Kobayashi and Y. Omura [arXiv:hep-ph/0708.3148].

[2] A. E. Nelson and N. Seiberg, Nucl. Phys. B **416**, 46 (1994) [arXiv:hep-ph/9309299].

[3] K. Intriligator, N. Seiberg and D. Shih, [arXiv:hep-th/0703281].

[4] K. Intriligator, N. Seiberg and D. Shih, JHEP **0604**, 021 (2006) [arXiv:hep-th/0602239].