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Nuclear Physics B 815 (2009) 240–255
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

Continuous degeneracy of non-supersymmetric vacua

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Received 11 February 2009; accepted 17 February 2009

Available online 23 February 2009

Abstract

In global supersymmetric Wess–Zumino models with minimal Kähler potentials, F-type supersymmetry breaking always yields instability or continuous degeneracy of non-supersymmetric vacua. As a generalization of the original O'Raifeartaigh's result, the existence of instability or degeneracy is true to any higher order corrections at tree level for models even with non-renormalizable superpotentials. The degeneracy generically coincides the R-axion direction under some assumptions of R-charge assignment, but generally requires neither R-symmetries nor any assumption of generic superpotentials. The result also confirms the well-known fact that tree level supersymmetry breaking is a very rare occurrence in global supersymmetric theories with minimal Kähler potentials. The implication for effective field theory method in the landscape is discussed and we point out that choosing models with minimal Kähler potentials may result in unexpected answers to the vacuum statistics. Supergravity theories or theories with non-minimal Kähler potentials in general do not suffer from the existence of instability or degeneracy. But very strong gauge dynamics or small compactification dimension reduces the Kähler potential from non-minimal to minimal, and gravity decoupling limit reduces supergravity to global supersymmetry. Instability or degeneracy may appear in these limits. Away from these limits, a large number of non-SUSY vacua may still be found in an intermediate region.

1. Introduction

It is known ever since the discovery of spontaneous supersymmetry breaking [1,2] that there is a massless Goldstino in any SUSY breaking theory involving chiral fields, i.e. Wess–Zumino models [3]. One related result is that such a non-SUSY vacuum has continuous degeneracy, a.k.a. pseudomoduli space or flat direction. This result has been proven for any renormalizable

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0550-3213/$ – see front matter
doi:10.1016/j.nuclphysb.2009.02.020

Lagrangian [1]. The result also shows that metastable SUSY breaking is a very rare occurrence in global SUSY theories with minimal Kähler potentials. In generic cases, non-SUSY extrema usually have mass matrices with negative eigenvalues which indicate tachyonic instability. Only with fine tuning of the potential does the non-SUSY vacuum has a vanishing mass matrix and remains stable up to quadratic. The degeneracy is true only at tree level. Loop corrections [4] lift up the flat direction and generate a potential for the moduli. That is why the degeneracy is also called "pseudomoduli" space.

There is a connection between SUSY breaking and R-symmetries described by Nelson–Seiberg theorem [5]. For a generic model without fine tuning, a U(1) R-symmetry for the superpotential is a necessary and sufficient condition for SUSY breaking. The R-symmetry needs to be broken to have non-zero Majorana gaugino masses. If the breaking is spontaneous, it implies the existence of a massless Goldstone boson, the R-axion, which coincides the degeneracy in many, but not all, O'Raifeartaigh's models considered to date. This statement is not true for some non-generic superpotential. There are exceptions where R-symmetries do not guarantee SUSY breaking, or SUSY is broken without any R-symmetry. Moreover, Nelson–Seiberg theorem only tells the non-existence of SUSY vacua, but does not guarantee the (meta)stability of any specific non-SUSY vacuum. As we show later in this paper, models with the coincidence of the R-axion and the degeneracy share some characteristic R-charge assignment. But the existence of continuous degeneracy is a more general result, requires neither the existence of R-symmetries nor the assumption of generic superpotentials.

Recent studies of effective field theory method in the string landscape [6,7] suggest that a large number of metastable non-SUSY vacua is only possible due to higher order corrections in the Kähler potential (or supergravity corrections, which we discuss later). In a simple example with a minimal Kähler potential and a non-renormalizable superpotential of a single chiral field [7], it is shown that any non-SUSY extremum is either a saddle point or has exact continuous degeneracy. The latter case requires a series of coefficients to be set to zero, which makes the occurrence of non-SUSY vacua very rare. The purpose of this paper is to investigate the general case with arbitrary number of chiral fields, i.e.:

Theorem. *In any global supersymmetric Wess–Zumino model with a minimal Kähler potential, an arbitrary number of chiral fields and a superpotential which can be any renormalizable or non-renormalizable holomorphic function of chiral fields, F-type SUSY breaking always yields instability or exact continuous degeneracy of the non-SUSY vacuum at tree level.*

A proof of the result has been provided in [8]. In this paper we demonstrate the proof in a different notation which gives insight to some related questions, e.g. the direction of the degeneracy and the relation to R-symmetries and the R-axion. We also emphasize the existence of instability if there is no degeneracy, which composes the base of the argument for the implication for the landscape. One should notice that simply integrating out extra fields and reducing to one field problem does not work, since this usually leads to a non-minimal Kähler potential which invalidates the proof. To make a rigorous proof, it is necessary to study the "full" theory with all chiral fields present.

Surely there are many situations which fall outside the scope of this theorem. The metastability is only a local result except along the degeneracy direction. So there may be some SUSY "true" vacuum separated from the non-SUSY one by a potential wall. The theorem can only be applied to F-type SUSY breaking in a low energy effective Wess–Zumino theory. SUSY breaking by Fayet–Iliopoulos terms [9] is not discussed in this paper. There are a class of calculable