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Quantum no-scale regimes and moduli dynamics

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Abstract

We analyze quantum no-scale regimes (QNSR) in perturbative heterotic string compactified on tori, with total spontaneous breaking of supersymmetry. We show that for marginal deformations initially at any point in moduli space, the dynamics of a flat, homogeneous and isotropic universe can always be attracted to a QNSR. This happens independently of the characteristics of the 1-loop effective potential $\mathcal{V}_{\text{1-loop}}$, which can be initially positive, negative or vanishing, and maximal, minimal or at a saddle point. In all cases, the classical no-scale structure is restored at the quantum level, during the cosmological evolution. This is shown analytically by considering moduli evolutions entirely in the vicinity of their initial values. Global attractor mechanisms are analyzed numerically and depend drastically on the sign of $\mathcal{V}_{\text{1-loop}}$. We find that all initially expanding cosmological evolutions along which $\mathcal{V}_{\text{1-loop}}$ is positive are attracted to the QNSR describing a flat, ever-expanding universe. On the contrary, when $\mathcal{V}_{\text{1-loop}}$ can reach negative values, the expansion comes to a halt and the universe eventually collapses into a Big Crunch, unless the initial conditions are tuned in a tiny region of the phase space. This suggests that flat, ever-expanding universes with positive potentials are way more natural than their counterparts with negative potentials.

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1. Introduction

To account for an extremely small cosmological constant, a natural starting point in supergravity is the class of no-scale models [1]. The latter describe the spontaneous breaking of local supersymmetry at a scale M that parameterizes a flat direction of a positive semi-definite potential. In perturbative string theory in d dimensions, this setup can be realized at tree level by coordinate-dependent compactification [2,3], which implements the Scherk–Schwarz mechanism [4]. The magnitude of the supersymmetry breaking scale measured in σ-model frame, $M_{(\sigma)}$, can be restricted to be lower than the string scale M_s, for Hagedorn-like instabilities [3,5] to be avoided. However, quantum effects lift in general the classical flat directions. At 1-loop, supposing for simplicity that there is no non-trivial mass scale lower than M, a contribution of order $(n_F - n_B)M^d$ to the effective potential is generated, where n_F and n_B are the numbers of massless fermionic and bosonic degrees of freedom. In this case, a mechanism responsible for the stabilization of M would generically yield a large cosmological constant. For this reason, the theories satisfying $n_F = n_B$, which are sometimes referred as "super no-scale models", have attracted attention [6–8], since their 1-loop effective potentials turn out to be exponentially suppressed. In some models, the potentials can even vanish exactly at 1-loop, at specific points in moduli space [9]. However, even in these instances, the smallness of the potential happens to be invalidated once Higgs masses lower than M are introduced [7,8], and/or generic higher order loop corrections are taken into account [10].

Alternatively, one may not assume the stabilization of the supersymmetry breaking scale. In this case, the motion of M induced by the effective potential may be analyzed in a cosmological framework [11,12], and eventually at finite temperature [12–15]. One of the main motivations of [11] was to find conditions (which we extend in the present paper) for flat, homogeneous and isotropic expanding universes to be allowed by the dynamics. In this reference, the analysis is done by taking into account a reduced set of fields, namely the volume vol of the torus involved in the Scherk–Schwarz supersymmetry breaking, the dilaton ϕ and the scale factor a of the universe. For convenience, the degrees of freedom associated with $\ln(vol)$ and ϕ are implemented by two canonical fields Φ and $\phi_\perp$. They are orthogonal linear combinations, where Φ is the "no-scale modulus" which satisfies $M \equiv e^{\alpha\Phi} M_s$, with α a normalization factor. The history of the universe described by a flat Friedmann–Lemaître–Robertson–Walker (FLRW) metric proves to depend drastically on the sign of the 1-loop effective potential[2]:

• For $n_F \geq n_B$, up to time reversal, the evolution is ever-expanding. At initial and late times, it is driven by the kinetic energies of Φ and $\phi_\perp$, which dominate over the quantum effective potential. As a result, the cosmological solution converges in both limits to classical ones, which are characterized by exact no-scale structures with free scalars Φ and $\phi_\perp$.[3] For this reason, the universe is said to be at early and late times in "quantum no-scale regime" (QNSR). It is only during an intermediate era that connects both QNSRs that the effective potential is relevant. The latter may even induce a transient period of acceleration.

• For $n_F < n_B$, up to time reversal, three different histories can be encountered. In two of them, the universe starts with a Big Bang dominated by the total energy (kinetic plus potential) of Φ. Then, it may forever expand by entering in QNSR, or it may reach a maximum size, before

[2] Technically, similar analyzes involving scalar fields with exponential potentials can be found in Ref. [16]. They can be realized at tree level in string theory, with backgrounds involving compact hyperbolic internal spaces, S-branes or non-trivial fluxes [17].

[3] These limit solutions become exact trajectories in the super no-scale models *i.e.* when $n_F - n_B = 0$.