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Moduli fields as quintessence and the chameleon

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Abstract

We consider models where moduli fields are not stabilized and play the role of quintessence. In order to evade gravitational tests, we investigate the possibility that moduli behave as chameleon fields. We find that, for realistic moduli superpotentials, the chameleon effect is not strong enough, implying that moduli quintessence models are gravitationally ruled out. More generally, we state a no-go theorem for quintessence in supergravity whereby models either behave like a pure cosmological constant or violate gravitational tests.

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1. Introduction

Dark energy and its properties is one of the most intriguing puzzles of present day theoretical physics. Indeed, there is convincing evidence, coming from SNIa supernovae [1], large scale structures of the universe [2–4] and the CMB anisotropies [5,6] which leads to the existence of an acceleration of the universe expansion in the recent past. When interpreted within the realm of General Relativity, these results imply the existence of a pervading weakly interacting fluid with a negative equation of state and a dominant energy density. The simplest possibility is of course a pure cosmological constant. This has the advantage of both fitting the data and incorporating a mild modification of the Einstein equations. Now it happens that the value of the cosmological constant is so small compared to high energy physics scales that no proper explanation for such a fine tuning has been found except maybe the anthropic principle [7] used in the context of a stringy landscape [8,9]. This is all the more puzzling in view of the very diverse sources of radiative corrections in the standard model of particle physics and beyond.

A plausible alternative involves the presence of a scalar field akin to the inflaton of early universe cosmology and responsible for the tiny vacuum energy scale [10–17]. These models of quintessence have nice features such as the presence of long time attractors (tracking fields) leading to a relative insensitivity to initial conditions [10]. In most cases, the quintessence runaway potentials lead to large values of the quintessence field now, of the order of the Planck mass. This immediately prompts the necessity of embedding such models in high energy physics where nearly Planck scale physics is taken into account. The most natural possibility is supergravity as it involves both supersymmetry and gravitational effects [18]. Moreover, superstring theories lead to supergravity models at low energy.

From the model building point of view, the quintessence field does not belong to the well-known sector of particles of the standard model. Therefore, one has to envisage a dark sector where this field lives and provide the corresponding Kähler, $K_{\rm quint}$, and super potentials $W_{\rm quint}$ in order to compute the quintessence scalar potential explicitly. Once a quintessence model has been built, one must also worry about the coupling to both matter and hidden sector supersymmetry breaking [19]. Indeed the rolling of the quintessence field can induce variations of constants such as the fine structure constants. Moreover the smallness of the mass

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of the quintessence field implies that its gravitational coupling to matter must be suppressed in order to comply with fifth force and equivalence principle violation experiments [20,21].

The observable sector is fairly well known and the hidden sector can be parameterized. Therefore, the main uncertainty comes from the dark sector, i.e., from the specific form chosen for $K_{\rm quint}$ and $W_{\rm quint}$. Recently, we have investigated this question for a class of models where the Kähler potential and the superpotential can be Taylor expanded or are given by polynomial functions of the (super) fields [22]. We have shown that this type of models, under the standard assumption of separate sectors (see also our conclusion), is in trouble as either they are uninteresting from the cosmological point of view (typically, in practice, they are equivalent to a cosmological constant) or they violate the bounds from gravity experiments (typically, they violate the bound on the fifth force and/or on the weak equivalence principle).

The aim of this Letter is to study a general class of models, probably the most natural one from a string theory point of view [23], where the quintessence field is a moduli field (Kähler moduli). Technically, this means that $K_{\rm quint}$ is taken to be a logarithm of the quintessence field [23]. Although the Kähler function is known, there is no specific standard choice for the superpotential which remains a free function. Therefore, we will derive model-independent results and then discuss the various cases that have been envisaged in the literature for $W_{\rm quint}$ (for instance, polynomial superpotentials and exponential ones à la KKLT [24]). We show that, for reasonable choices of $W_{\rm quint}$, the corresponding models are also in trouble from the gravity experiments point of view. This last result is in fact more subtle than in the case of the first class of models treated in Ref. [22]. Indeed, contrary to the polynomial models, a chameleon mechanism [25] can be present in the no scale case and could be used to protect the quintessence field from gravity problems. However, unfortunately, we show that this mechanism is in fact not sufficiently efficient to save no scale quintessence in simple cases such as gaugino condensation and polynomial superpotentials.

The Letter is arranged as follows. In Section 2, we establish some general results relevant to the no-scale models. In particular, in Section 2.1, we calculate the quintessence potential for a general moduli superpotential and in Section 2.2, we give the corresponding soft terms in the observable sector. In Section 2.3, we study how the electroweak transition is affected by the no-scale dark sector. Then, in Section 3, we briefly review the chameleon mechanism. In particular, in Section 3.1, we describe the thin shell phenomenon with, in Section 3.2, applications to the gaugino condensation case and in Section 3.3 to the polynomial case. In Section 4, we present our conclusions and state a no-go theorem for the compatibility between quintessence in supergravity and gravity experiments.

2. No-scale quintessence

2.1. The scalar potential

In this section we collect results related to the dynamics of Kähler moduli coming from string compactifications. In practice we only consider that there is a single moduli Q which can be seen as the breathing mode of the compactification manifold. The reduction from 10 dimensions to 4 dimensions leads to a no-scale structure for the Kähler potential of the moduli. The Kähler potential is given by the following expression

$$K_{\rm quint} = -\frac{3}{\kappa}\ln\left[\kappa^{1/2}\left(Q+Q^{\dagger}\right)\right], \tag{1}$$

where $\kappa \equiv 8\pi/m_{\rm Pl}^2$. The moduli Q has no potential and is a flat direction to all order in perturbation theory. In string theory, the validity of the supergravity approximation is guaranteed provided $\kappa^{1/2}Q \gg 1$, implying that the compactification manifold is larger than the string scale. A potential can be generated once non-perturbative effects are taken into account, this may lead to a superpotential

$$W_{\rm quint} = W_{\rm quint}(Q) \equiv M^3\mathcal{W}\left(\kappa^{1/2}Q\right), \tag{2}$$

which will be discussed later. The advantage of the above writing is that it emphasizes the scale M of the superpotential. The quantity $\mathcal{W}$ is dimensionless and of order one. Then, inserting the Kähler and the superpotentials into the expression of the scalar potential, one gets

$$V_{\rm quint}(Q) = -\frac{\kappa^{1/2}}{[\kappa^{1/2}(Q+Q^{\dagger})]^2}\left(W\frac{\partial W^{\dagger}}{\partial Q^{\dagger}} + W^{\dagger}\frac{\partial W}{\partial Q}\right) + \frac{1}{3\kappa^{1/2}(Q+Q^{\dagger})}\left|\frac{\partial W}{\partial Q}\right|^2. \tag{3}$$

The no-scale property implies that the term in $-3|W|^2$ in the supergravity potential cancels. The kinetic terms of the moduli read $3|\partial Q|^2/(Q+Q^{\dagger})^2$ implying that Q is not a normalized field. The normalized field q is given by

$$\kappa^{1/2}Q = \exp\left(-\sqrt{\frac{2}{3}}q\right), \tag{4}$$

where q is a dimensionless scalar field.