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Chromo-natural inflation in Supergravity

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ABSTRACT

We present supergravity realizations of chromo-natural inflationary models. We show that by using superpotentials with "imaginary" holomorphic functions of the inflaton one can obtain effective theories of inflation that are also consistent truncations of the original supergravity models.

1. Introduction

Natural inflationary models have the nice property of protecting the required flatness of the inflationary potential against radiative corrections by means of an approximate shift symmetry [1]. For instance, in the case of an axion field ϕ acquiring a potential from instanton corrections, the symmetry can be broken in a controlled way:

$$V(\phi) = \Lambda^4 \left(1 - \cos \frac{\phi}{f_\phi}\right). \tag{1}$$

While these models have been studied for many years (see [2] for a review), only recently they have been generalized to Supergravity, keeping the stabilization of the other fields under control [3]. All these models, however, suffer the fact that a greater than planckian axion decay constant f_ϕ is needed, which seems to be very difficult to embed in string theory [4,5]. Modifications of this scenario to solve this problem have been proposed [6], usually by introducing additional axion fields or by creating conditions for a transplanckian evolution of the inflation or by slowing down the axion evolution through particle production. This last mechanism has been used in inflationary scenarios involving gauge fields [7] and in particular in the so-called chromo-natural inflation scenario [8], where the axion couples to the topological term of an SU(2) triplet of gauge fields:

$$S = \int d^4x\sqrt{-g}\left[\frac{M_P}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) - \frac{1}{4}\mathrm{Tr}(F_{\mu\nu}F^{\mu\nu}) + \frac{g_\phi}{8\sqrt{-g}}\,\frac{\phi}{f_\phi}\,\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(F_{\mu\nu}F_{\rho\sigma})\right]. \tag{2}$$

If the vector fields acquire an isotropic vacuum expectation value during inflation[1]

$$A_0^I = 0, \quad A_a^I = \delta_a^I\, Q(t), \tag{3}$$

the modification to the axion equations of motion are such that the inflaton can be in slow roll also for potentials that would otherwise be too steep to support inflation. In addition to the force from the axion potential there is in fact a magnetic force proportional to g_ϕ, acting as a friction term and hence granting the slow roll of the inflaton. While this scenario allows for sub-planckian f_ϕ, the number of e-folding that can be obtained depends crucially on g_ϕ, which should be sufficiently large [5].

Also this model has been studied for various years and various modifications to make it compatible with the observed data have been proposed (see for instance [9]). However, a Supergravity embedding, which is a first step to find its embedding in an ultraviolet complete theory of quantum gravity like string theory,

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[1] Here and in what follows $I, J = 1, 2, 3$ are the SU(2) gauge indices of the adjoint representation and $a = 1, 2, 3$ labels the space coordinates $x^\mu = \{x^0, x^a\}$.

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is still missing. In this note we fill this gap, by providing Supergravity models that consistently reproduce various models of chromo-natural inflation as effective theories. We also comment on the possible generation of the various ingredients from string theory.

2. Natural inflation in Supergravity

The first step in our construction is the embedding of natural inflationary models in Supergravity. The first example of such embedding was provided in [3], where various Supergravity models have been constructed, leading to effective theories compatible with natural inflation. In all the models presented in [3] the superpotential is linear in the goldstino superfield S and the Kähler potential is a function of only the real or imaginary part of the inflaton superfield Φ, so as to avoid the Supergravity η-problem. While most of these models do not give consistent truncations to the inflaton alone, the sgoldstino acts as a stabilizer, generating a large effective mass for the partner of the axion and for itself, so that one can produce effective models with an axion potential of the form (1).

In what follows we first review and refine the construction presented in [3] by building Supergravity models that allow for effective theories of natural inflation that are also consistent truncations, i.e. such that solutions to the effective theory equations of motion are also exact solutions of the full model. We do this following the ideas presented in [10]. Since we will also be interested in models with two light inflaton fields, we introduce two Kähler potentials, with the same structure, depending on the inflatons Φ_i and on the stabilizers S_i as

$$K_i = \frac{1}{2}\,(\Phi_i+\bar\Phi_i)^2 + S_i\bar S_i - \frac{b}{M_P^2}\,(S_i\bar S_i)^2. \tag{4}$$

Introducing canonically normalized fields

$$\Phi_i = \frac{1}{\sqrt{2}}\,(\alpha_i + i\,\phi_i)\,, \tag{5}$$

we see that the Kähler potentials (4) and consequently the scalar σ-models have shift symmetries $\phi_i \to \phi_i + c_i$, while the parameter b is introduced for stabilization of S at $S=0$. We also introduce a superpotential that is a linear combination of

$$W_i = S_i\,\mathscr{F}_i\left(\frac{\Phi_i}{f_\phi}\right), \tag{6}$$

where $\mathscr{F}_i$ are "imaginary" holomorphic functions, namely they satisfy

$$\overline{\mathscr{F}_i(z)} = \mathscr{F}_i(-\bar z). \tag{7}$$

Whenever these functions can be given in terms of a power series, their general expansion is

$$\mathscr{F}_i(z) = \sum_n a_n (iz)^n, \tag{8}$$

for $a_n \in \mathbb{R}$. The objective is to have a scalar potential that is even in the α_i fields so that we can consistently truncate them to zero. Given the structure of the Kähler potential (4) and superpotential (6), the same result can be obtained if all the a_n coefficients are imaginary. This corresponds to the constraint $\overline{\mathscr{F}_i(z)} = -\mathscr{F}_i(-\bar z)$ and the extra imaginary factor in $\mathscr{F}_i$ can be safely reabsorbed in the corresponding S_i field, without changing the resulting model. Altogether these ingredients give a scalar potential

$$V = e^{K/M_p^2}\left(g^{i\bar\jmath} D_i W\, D_{\bar\jmath}\overline{W} - 3\frac{|W|^2}{M_p^2}\right), \tag{9}$$

which can be consistently truncated to configurations where $S_i = 0 = \Phi_i + \bar\Phi_i$. In fact the scalar potential depends at least quadratically on the S_i fields and it is even with respect to the α_i fields, i.e.

$$\partial_{S_i} V|_* = \partial_{\alpha_i} V|_* = 0, \tag{10}$$

where $|_*$ denotes the evaluation of the quantity at $S_i = \alpha_i = 0$. The truncated scalar potential is then

$$V|_* = \sum_i \left|\mathscr{F}_i\left(\frac{i}{\sqrt{2}}\frac{\phi_i}{f_\phi}\right)\right|^2 \tag{11}$$

and the masses of the other fields along the ϕ_i directions are

$$\begin{aligned} \frac{M_p^2\, m^2_{Re\,S_i}}{V|_*} &= \frac{M_p^2\, m^2_{Im\,S_i}}{V|_*} = 4b - \frac{M_p^2}{f_\phi^2}\left[\frac{\mathscr{F}_i'|_*}{\mathscr{F}_i|_*}\right]^2, \\ \frac{M_p^2\, m^2_{\alpha_i}}{V|_*} &= 2 - \frac{M_p^2}{f_\phi^2}\left[\frac{\mathscr{F}_i'|_*}{\mathscr{F}_i|_*}\right]^2 + \frac{M_p^2}{f_\phi^2}\frac{\mathscr{F}_i''|_*}{\mathscr{F}_i|_*}. \end{aligned} \tag{12}$$

These are naturally of the order of the Hubble parameter for choices of $\mathscr{F}_i$ leading to inflationary potentials and for choices of b that do not require fine tuning.

To reproduce the scalar potential (1) we can take only the first copy of S and Φ fields and set $\mathscr{F}_1|_* = \sqrt{2}\,\Lambda^2 \sin\left(\frac{\phi_1}{2 f_\phi}\right)$, which means

$$\mathscr{F}_1(\Phi_1) = i\,\sqrt{2}\,\Lambda^2 \sinh\left(\frac{1}{\sqrt{2}}\frac{\Phi_1}{f_\phi}\right). \tag{13}$$

This corresponds to Model 3 in [3], which provides indeed a consistent truncation and not just an effective theory of natural inflation. The other options presented in [3] do not lead to consistent truncations, but they give otherwise well-defined effective theories.

More options are available if one uses non-linear representations of supersymmetry. As shown in recent times, one has more functional freedom when using non-linear supersymmetry in Supergravity and one can therefore accommodate more easily inflationary models, satisfying all consistency requirements [12]. For instance one could obtain a scalar potential of the form (11) by introducing two constrained chiral superfields X and Y, satisfying $X^2 = 0 = XY = 0$ in a model with Kähler potential [13]

$$K = \frac{1}{2}(\Phi_1+\bar\Phi_1)^2 + \frac{1}{2}(\Phi_2+\bar\Phi_2)^2 + X\bar X + Y\bar Y \tag{14}$$

and superpotential

$$W = \Lambda^2\,(X\mathscr{F}_1 + Y\mathscr{F}_2)\,. \tag{15}$$

Actually, one could also constrain the Φ_i fields by setting $X(\Phi_i + \bar\Phi_i) = 0$ and produce a direct truncation to the axion fields ϕ_i [14], while at the same time removing the constraint on the $\mathscr{F}_i$ functions to be "imaginary" holomorphic. This in turn would allow for an easy embedding as consistent truncations also of the other models presented in [3]. The only delicate point in doing this is that consistency requires supersymmetry to be broken also at the exit of inflation, which implies that $\mathscr{F}_i \neq 0$ everywhere in field space. This is however a small adjustment that can be easily incorporated in the description by adding a sufficiently small constant term in (15).