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Scale invariant Volkov–Akulov supergravity

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ABSTRACT

A scale invariant goldstino theory coupled to supergravity is obtained as a standard supergravity dual of a rigidly scale-invariant higher-curvature supergravity with a nilpotent chiral scalar curvature. The bosonic part of this theory describes a massless scalaron and a massive axion in a de Sitter Universe.

1. Introduction

Motivated by single-field inflationary scenarios [1], several sgoldstinoless [2–5] supergravity extensions of inflationary models were recently considered [6–11] (for a recent review see [12]). Interestingly enough, in [7,11] many of these models were linked to pure higher-derivative supergravity with a nilpotency constraint on the scalar curvature chiral superfield $\mathcal{R}$. These include the Volkov–Akulov–Starobinsky model [7] and the pure Volkov–Akulov theory coupled to supergravity [7]. Recently, the full component form of the latter theory was presented in [13,14].

Along these lines, various authors considered R^2 theories of gravity [15] and their supergravity embeddings [15,16], which possess a rigid scale invariance and naturally accommodate a de Sitter Universe. It is the aim of this note to give the sgoldstinoless version of these theories, which naturally combines an enhanced rigid scale invariance and a de Sitter geometry. This theory also emerges as a limiting case of the inflationary scenario.

2. Scale-invariant nilpotent supergravity

The superspace action density of the scale-invariant theory that we consider,[3]

$$\mathcal{A} = \left.\frac{\mathcal{R}\overline{\mathcal{R}}}{g^2}\right|_D + \left.\sigma\mathcal{R}^2 S_0 + \text{h.c.}\right|_F , \tag{2.1}$$

where g is a dimensionless parameter, is invariant under the rigid scale transformations

$$\mathcal{R} \to \mathcal{R},\ S_0 \to e^{-\lambda} S_0,\ \sigma \to e^{\lambda}\sigma . \tag{2.2}$$

This theory is equivalent to the theory considered in [16], supplemented with the nilpotency constraint

$$\mathcal{R}^2 = 0, \tag{2.3}$$

which is enforced by the chiral Lagrange multiplier σ present in the second term of eq. (2.1).

Using manipulations similar to those originally introduced in [17], we can now turn this model into a scale-invariant version of the Volkov–Akulov model coupled to standard supergravity. To this end, we first use the superspace identity

$$\left.\sigma\mathcal{R}^2 S_0 + h.c.\right|_F = \left.\left(\sigma\frac{\mathcal{R}}{S_0} + \overline{\sigma}\frac{\overline{\mathcal{R}}}{\overline{S}_0}\right) S_0\overline{S}_0\right|_D + \text{tot. deriv.}, \tag{2.4}$$

and then introduce two Lagrange chiral superfield multipliers T and S according to

$$\mathcal{A} = \left.\left(\sigma S + \overline{\sigma}\overline{S} + \frac{S\overline{S}}{g^2}\right) S_0\overline{S}_0\right|_D - \left.T\left(\frac{\mathcal{R}}{S_0} - S\right) S_0^3 + \text{h.c.}\right|_F . \tag{2.5}$$

The final result is the standard supergravity action density

$$\mathcal{A} = -\left.\left(T + \overline{T} - \sigma S - \overline{\sigma}\overline{S} - \frac{S\overline{S}}{g^2}\right) S_0\overline{S}_0\right|_D + \left.T S S_0^3 + \text{h.c.}\right|_F + \text{tot. deriv.} \tag{2.6}$$

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A final shift and a redefinition according to

$$T \to T + \sigma S, \qquad X = \frac{S}{g} \tag{2.7}$$

yield the standard supergravity action density

$$\mathcal{A} = -(T + \overline{T} - X\overline{X}) S_0 \overline{S}_0 \Big|_D + W(T, X) S_0^3 + \text{h.c.} \Big|_F , \tag{2.8}$$

where

$$W(T, X, \sigma) = gTX + g^2 \sigma X^2 . \tag{2.9}$$

This is tantamount to the scale-invariant superpotential

$$W(T, X) = gTX, \tag{2.10}$$

where X is subject to the nilpotency constraint

$$X^2 = 0, \tag{2.11}$$

so that X describes the sgoldstinoless Volkov–Akulov multiplet [2–5]. The corresponding bosonic Lagrangian,

$$\mathcal{L} = \frac{R}{2} - \frac{3}{(T + \overline{T})^2} |\partial T|^2 - g^2 \frac{|T|^2}{3(T + \overline{T})^2}, \tag{2.12}$$

is a special case of the result displayed in [7], so that it describes an $SU(1,1)/U(1)$ Kählerian model of curvature $-2/3$ with a scale-invariant positive potential. As a result, in terms of the canonical variable

$$T = e^{\phi\sqrt{\frac{2}{3}}} + ia\sqrt{\frac{2}{3}}, \tag{2.13}$$

one finds

$$\mathcal{L} = \frac{R}{2} - \frac{1}{2}(\partial\phi)^2 - \frac{1}{2} e^{-2\phi\sqrt{\frac{2}{3}}} (\partial a)^2 - \frac{g^2}{12} - \frac{g^2}{18} e^{-2\phi\sqrt{\frac{2}{3}}} a^2 . \tag{2.14}$$

Note that in the Einstein frame the metric is inert under the scale transformation corresponding to eq. (2.2), while

$$\phi \to \phi + \gamma, \quad a \to e^{\gamma\sqrt{\frac{2}{3}}} a. \tag{2.15}$$

3. de Sitter vacuum geometry

Since a is stabilized at zero, this model results in a de Sitter vacuum geometry, with a corresponding scale-invariant realization of supersymmetry breaking induced by the non-linear sgoldstinoless multiplet. The supersymmetry breaking scale M_s^2 is

$$M_s^2 = \frac{g}{2\sqrt{3}} M_{Planck}^2, \tag{3.1}$$

up to a conventional numerical factor. Eq. (2.8) describes the minimal supergravity model that embodies a scale-invariant goldstino interaction and leads unavoidably to a de Sitter geometry. This model involves a single dimensionless parameter g, which determines its *positive* vacuum energy according to

$$V = \frac{g^2}{12} M_{Planck}^4 . \tag{3.2}$$

In contrast, the Volkov–Akulov model coupled to supergravity, depends on the two parameters f and W_0, and consequently leads to a vacuum energy [18–20,7,13]

$$V = \frac{1}{3} |f|^2 - 3 |W_0|^2 \tag{3.3}$$

of arbitrary sign.

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