Inflation in Supergravity from Massive Vector Multiplets

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work with
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Relevant work

- FF, von Unge, "Naturalness and Chaotic Inflation in Supergravity from Massive Vector Multiplets," arXiv:1404.3739 [hep-th].
- Ferrara, Kallosh, Linde, Porrati, "Higher Order Corrections in Minimal Supergravity Models of Inflation," JCAP **1311**, 046 (2013) arXiv:1309.1085 [hep-th].
- Ferrara, Kallosh, Linde, Porrati, "Minimal Supergravity Models of Inflation," Phys. Rev. D **88**, no. 8, 085038 (2013) arXiv:1307.7696 [hep-th].
- FF, Kehagias, Riotto, "On the Starobinsky Model of Inflation from Supergravity," Nucl. Phys. B **876**, 187 (2013) arXiv:1307.1137 [hep-th].

- There is evidence that our universe went through an Inflationary phase in its early life. The simplest choice is a scalar field (Inflaton).
- Every physical theory beyond the Standard Model should be able to account for the existence of such a phase.
- A theory which naturally incorporates and theoretically explains the existence of scalar particles is Supersymmetry.
- In theories of supersymmetry the only correct framework to study inflation is Supergravity.

The simplest favored by observations inflationary potential is

$$\mathcal{V} = \frac{1}{2} m^2 \phi^2. \qquad \text{Linde '83} \tag{1}$$

To embed (1) into supergravity the usual issues are

- Identify the one and only scalar which drives inflation.
- Stabilize the other scalars, and explain why they do not ruin inflation.
- Higher order corrections may spoil inflation; the notorious η-problem.

Natural chaotic inflation in supergravity

Kawasaki, Yamaguchi, Yanagida '00

Standard supergravity coupled to two chiral superfields.

- With Kähler potential

$$K = (\Phi + \bar{\Phi})^2 + S\bar{S}. \tag{2}$$

- With superpotential

$$W = m\Phi S. \tag{3}$$

- The almost exact shift symmetry

$$\Phi \to \Phi + icM_P \tag{4}$$

controls the higher order corrections.

During inflation

- The scalar potential becomes

$$\mathcal{V} \sim \frac{1}{2} m^2 \varphi^2 (1 + \eta^2) + m^2 |S|^2. \tag{5}$$

- One inflaton & stabilized fields

$$\langle S \rangle = 0 \ , \ \langle \eta \rangle = 0 \ , \ \varphi = \text{inflaton}. \tag{6}$$

- Various proposals for embedding chaotic inflation in supergravity. Kallosh, Linde '10, Kallosh, Linde, Rube '11, Ferrara, Kehagias, Riotto '14, Ellis, Garcia, Nanopoulos, Olive '14

Is there an easier way to achieve this?

Outline

Real linear multiplets in new-minimal supergravity

Chaotic inflation in new-minimal supergravity

Chaotic inflation in old-minimal supergravity

Conclusions

Flashing superspace

see for example Wess, Bagger '92

- Supersymmetry is better formulated by utilizing a space with auxiliary anti-commuting coordinates.
- In $4D$, $\mathcal{N} = 1$ all we need is

$$\begin{aligned} \{D_\alpha, \bar{D}_{\dot{\alpha}}\} &= -2i\sigma^a_{\alpha\dot{\alpha}}\partial_a \\ \{D_\alpha, D_\beta\} &= 0 \\ \{\bar{D}_{\dot{\alpha}}, \bar{D}_{\dot{\beta}}\} &= 0 \\ [D_\alpha, \partial_a] &= [\bar{D}_{\dot{\alpha}}, \partial_a] = 0. \end{aligned} \tag{7}$$

- These relations are improved in supergravity by curvature and torsion terms.

New-minimal supergravity

Sohnius, West '81, Ferrara, Sabharwal '89

- The spectrum is

$$e_m^a\,, \quad \psi_m^\alpha\,, \quad A_m\,, \quad B_{mn}. \tag{8}$$

- The supergravity Lagrangian is

$$e^{-1}\mathcal{L} = \frac{1}{2}M_P^2\,R + \bar{\psi}^a r_a + 2M_P^2\,A_a H^a - 3M_P^2\,H_a H^a. \tag{9}$$

- On-shell both auxiliary fields vanish

$$H_m = 0 = \epsilon^{mnrs}\partial_m A_n. \tag{10}$$

- The supercovariant derivatives become

$$D_A \to \nabla_A. \tag{11}$$

Real linear superfields in new-minimal supergravity

Ovrut, Schweibert '89, Ferrara, Sabharwal '89

- The real linear superfield is defined as

$$\nabla^\alpha \nabla_\alpha L = \bar{\nabla}_{\dot{\alpha}} \bar{\nabla}^{\dot{\alpha}} L = 0. \tag{12}$$

- With bosonic components

$$L| = \phi \ , \ -\frac{1}{2}[\nabla_\alpha, \bar{\nabla}_{\dot{\alpha}}]L| = h_{\alpha\dot{\alpha}}. \tag{13}$$

- The field h_m is constrained

$$h_m = -\frac{1}{2}\epsilon_{mnrs}\partial^n b^{rs} - 2\phi H_m \tag{14}$$

and b_{mn} is the two form of the real linear multiplet.

Real linear superfield & shift symmetry

- The free theory is

$$-\int d^4\theta E L^2 = -\frac{1}{2} e\partial\phi\partial\phi + \frac{1}{2} e h_m h^m + \text{fermions}. \qquad (15)$$

- There is a shift symmetry

$$L \to L + c\, M_P. \qquad (16)$$

- Higher order terms are forbidden

$$-\frac{1}{(\text{some scale})^4}\int d^4\theta E L^4 \to \text{violates symmetry}. \qquad (17)$$

Coupling to gauge superfields

- A gauge invariant coupling

$$-gM\int d^4\theta ELV = -\frac{1}{2}egM\phi \mathrm{D} + \frac{1}{2}egMv_m\left(h^m + 2\phi H^m\right) \quad (18)$$

leads to a small violation of the shift symmetry for

$$gM << M_P. \quad (19)$$

- Higher order corrections are now allowed but are expected to be small 't Hooft '80

$$-\frac{1}{(\text{some scale})^4}\int d^4\theta EL^4 \rightarrow \text{naturally suppressed.} \quad (20)$$

Massive vector multiplets in new-minimal supergravity

- The full superspace theory is

$$\mathcal{L} = -2M_P^2 \int d^4\theta\, E\, V_{\mathrm{R}} + \frac{1}{4}\left[\int d^2\theta\, \mathcal{E}\, W^2(V) + h.c.\right]$$
$$-gM \int d^4\theta\, E\, LV - \int d^4\theta\, E\, L^2 \qquad (21)$$
$$= \text{massive vector multiplet coupled to SUGRA.}$$

- The bosonic sector reads

$$e^{-1}\mathcal{L} = \frac{1}{2}M_P^2 R - \frac{1}{2}\partial\phi\partial\phi - \frac{g^2}{8}M^2\phi^2$$
$$-\frac{1}{4}F^{mn}F_{mn}(v) - \frac{1}{8}g^2 M^2 v^m v_m. \qquad (22)$$

- The b_{mn} field (1 scalar DOF) has been eaten by the massive vector field via a Stueckelberg mechanism .

Chaotic inflation in supergravity

From massive vector superfields

- The inflationary sector is

$$e^{-1}\mathcal{L}_{infl} = \frac{1}{2}M_P^2 R - \frac{1}{2}\partial\phi\partial\phi - \frac{m^2}{2}\phi^2 \tag{23}$$

where

$$m = \frac{1}{2}gM. \tag{24}$$

- Indeed the model is protected from higher order corrections since for inflation

$$m \sim 10^{13} GeV << M_P. \tag{25}$$

- No extra scalars to stabilize!

- We have seen how massive vector superfields reproduce single-field inflationary models . FF, Kehagias, Riotto '13, Ferrara, Kallosh, Linde, Porrati '13
- Chaotic models were only recently found. Ferrara, Kallosh, Linde, Porrati '13
- The quadratic model naturally evades the η-problem. FF, von Unge '14
- The terms we studied reproduce the 4D analog of the Green-Schwarz mechanism, they should arise from consistent superstring theories. Cecotti, Ferrara, Girardello '87, Lopes Cardoso, Ovrut '92
- The specific couplings are not *ad hoc*, they are motivated by a more fundamental theory.

Old-minimal supergravity

see for example Wess, Bagger '92

- The spectrum is

$$e_m^a\,, \quad \psi_m^\alpha\,, \quad M\,, \quad b_m. \tag{26}$$

- The supergravity Lagrangian is

$$e^{-1}\mathcal{L} = \frac{1}{2}R + \bar{\psi}^a r_a - \frac{1}{3}M\bar{M} + \frac{1}{3}b_a b^a. \tag{27}$$

- On-shell both auxiliary fields vanish

$$M = 0 = b_n. \tag{28}$$

- The supercovariant derivatives become

$$D_A \to \mathcal{D}_A. \tag{29}$$

Real linear superfields in old-minimal supergravity

see for example Binetruy, Girardi, Grimm '01

- The definition of a real linear superfield is

$$(\bar{\mathcal{D}}^2 - 8\mathcal{R})\mathcal{Q} = 0. \tag{30}$$

- The shift symmetry

$$\mathcal{Q} \to \mathcal{Q} + cM_P \tag{31}$$

  does not preserve supersymmetry since it violates the constraint (30).

- There is no shift symmetry for the old-minimal supergravity embedding.

Massive vector superfields in old-minimal supergravity

Van Proeyen '80

- The superspace coupling is

$$\mathcal{L} = \frac{1}{4}\int d^2\Theta\, 2\mathcal{E}\, W^2(V) + c.c. + \int d^2\Theta\, 2\mathcal{E}\left\{-\frac{1}{8}(\bar{\mathcal{D}}^2 - 8\mathcal{R})\mathcal{Z}(V)\right\} + c.c. \quad (32)$$

- With bosonic sector

$$e^{-1}\mathcal{L} = \frac{1}{2}M_P^2 R + \frac{1}{2}M_P^2\mathcal{J}''\partial C\partial C - \frac{1}{2}M_P^4(\mathcal{J}')^2 - \frac{1}{4}F^{mn}F_{mn}(v) + \frac{1}{2}M_P^2\mathcal{J}''v^m v_m \quad (33)$$

where

$$\mathcal{J}(C) = \frac{3}{2}\ln\left[-\frac{1}{3M_P^2}\mathcal{Z}(C)\right]. \quad (34)$$

Chaotic inflation in supergravity

From massive vector superfields

- For

$$\mathcal{Z}(V) = -3M_P^2 e^{-\frac{m^2}{3M_P^2}V^2} \tag{35}$$

the inflationary sector is

$$e^{-1}\mathcal{L}_{infl} = \frac{1}{2}M_P^2 R - \frac{1}{2}\partial\phi\partial\phi - \frac{m^2}{2}\phi^2 \tag{36}$$

where

$$\psi = mC. \tag{37}$$

- There is no reason to expect the specific form (35) - the theory needs a significant amount of fine tuning of the higher order terms.
- Still no extra scalars to stabilize!

Conclusions

- In supersymmetry scalars come in pairs.
- Here the second scalar is eaten by the massive vector.
- In supergravity one faces the η-problem.
- A shift symmetry controls the higher order corrections.
- Coupling to matter and cosmological properties?

Thank you!