Inflation and SUSY Breaking from Higher Curvature Supergravity

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CSI Corfu 2014
related work in supergravity


phenomenology needs

- Supersymmetry can offer answers to long-standing theoretical questions in particle physics.

Experiments and observations are pressing supersymmetry to account for more and more...

- Early time cosmology: The inflationary sector to drive inflation (or appropriate sectors for alternative models).

- LHC Physics: A hidden sector to break supersymmetry (and mediate it).

- Do we really need to introduce new sectors?
theory offers

- All supersymmetric models are coupled to supergravity.

- Supergravity is *always* accompanied by curvature higher derivatives.

- Higher derivative supergravity not only comes for free - it is obligatory!

Can this sector accommodate inflation / supersymmetry breaking?
But supersymmetry breaking needs superfields.

And inflation needs more superfields.

Where are these superfields hidden?
outline

New DOF?

$R + R^2$ supergravity

SUSY breaking and cosmic inflation from pure supergravity

Conclusions
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Conclusions
we start from gravity
Starobinsky ’80, Whitt ’84

- Higher curvature gravitation (Starobinsky model of inflation)

\[ e^{-1} \mathcal{L} = -\frac{1}{2} R + \frac{\alpha}{4} R^2. \]  (1)

- Higher derivative but ghost free!

- We can write (1) as

\[ e^{-1} \mathcal{L} = \left( -\frac{1}{2} + \frac{\alpha}{2} \phi \right) R - \frac{\alpha}{4} \phi^2. \]

- Finally after the rescaling the metric we find Einstein gravity coupled to a scalar (the scalaron)

\[ e^{-1} \mathcal{L} = -\frac{1}{2} R - \frac{1}{2} \partial \phi \partial \phi - \frac{1}{4\alpha} \left( 1 - e^{-\sqrt{\frac{2}{3}} \phi} \right)^2. \]
Two methods have been followed to embed the Starobinsky model in supergravity (in superspace)

- Couple superfields to standard supergravity and try to reproduce the potential.
- Embed the higher derivative $R + R^2$ to the minimal supergravities.
- The methods are equivalent.

Here we take the geometrical method as a guide

- We only employ the supergravity multiplet.
Supersymmetrization of Einstein gravity.

The spectrum is
\[ e^a_m, \psi^\alpha_m, M, b_m. \]

The supergravity Lagrangian is
\[ e^{-1} \mathcal{L} = -\frac{1}{2} R + \bar{\psi}^a r_a - \frac{1}{3} M \bar{M} + \frac{1}{3} b_m b^m. \]  

The fields \( M \) and \( b_m \) are auxiliary fields - they are part of the supermultiplet - they don’t propagate in (2).
superspace


- A space with auxiliary anti-commuting coordinates.
- Manifest supersymmetry in all stages.
- In 4D, $\mathcal{N} = 1$ all we need is

\[
(D_C D_B - (-)^{bc} D_B D_C) V^A = - T^D_{CB} D_D V^A + (-)^{d(b+c)} V^D R^A_{CBD}.
\]

- Superfields contain all the components of a multiplet.
chiral superfields

- Defined as
  \[ \bar{D}_{\dot{\alpha}} \Phi_i = 0. \]

- With chiral expansion
  \[ \Phi_i = A_i + \sqrt{2} \Theta^\alpha \psi_{\dot{\alpha} i} + \Theta^2 F_i. \]

- The coupling to standard supergravity reads
  \[ \mathcal{L} = \int d^2 \Theta 2 \mathcal{E} \left[ \frac{3}{8} (\bar{D}^2 - 8R) e^{-\frac{1}{3}K(\Phi_i, \bar{\Phi}_i)} + \mathcal{W}(\Phi_i) \right] + \text{c.c.} \]

- In component form (the bosonic sector) reads
  \[ e^{-1} \mathcal{L} = -\frac{1}{2} R - K_{\bar{i}j} \partial A^i \partial \bar{A}^\bar{j} \]
  \[ - e^K \left[ (K^{-1})^{\bar{i}j} (W_i + K_i W)(\bar{W}_j + K_j \bar{W}) - 3 W \bar{W} \right]. \]
The geometric objects of gravitation reside inside appropriate superfields.

- The Ricci superfield

\[ \bar{D}_{\dot{\alpha}} \mathcal{R} = 0 \]

with lowest component the auxiliary field \( M \)

\[ \mathcal{R} \big| = -\frac{1}{6} M \]

and the highest contains the Ricci scalar

\[ \mathcal{D}^2 \mathcal{R} \big| = -\frac{1}{3} R + \frac{4}{9} M \bar{M} + \frac{2}{9} b^a b_a - \frac{2i}{3} e^m_a \mathcal{D}_m b^a + \cdots \]
From the superfield $\mathcal{R}$ we build the superspace Lagrangian

$$-3 \int d^4 \theta E \mathcal{R} \bar{\mathcal{R}} = \frac{\alpha}{4} R^2 - \alpha \partial M \partial \bar{M} + \alpha (\nabla b)^2 + \cdots$$

This coupling gives rise to the additional propagating scalar degrees of freedom

- $M$: 2 real scalar degrees of freedom,
- $\nabla^m b_m$: 1 real scalar degree of freedom,
- $R^2 \rightarrow$ scalaron: 1 real scalar degree of freedom.

The 4 new scalar DOF reside inside appropriate superfields.
Higher derivative supergravity is equivalent to standard supergravity coupled to matter.

- The generic supergravity is

\[ \mathcal{L} = -3 \int d^4 \theta \ E f(\mathcal{R}, \bar{\mathcal{R}}) \]

- Equivalent to

\[ \mathcal{L} = -3 \int d^4 \theta \ E f(S, \bar{S}) + \int d^2 \Theta \ 2\varepsilon \ 6\mathcal{T} (S - \mathcal{R}) \]

where \( \mathcal{T} \) works as a Lagrange multiplier.

- The red terms contribute to the Kähler potential and the superpotential.
equivalent theories to HD supergravity II
Cecotti, ’87

- From the identity

\[-6 \int d^2\Theta 2\varepsilon \mathcal{R}\mathcal{T} + \text{c.c.} = -3 \int d^4\theta E (\mathcal{T} + \bar{\mathcal{T}})\]

the remaining term is also Kähler potential.

- The HD supergravity is equivalent to standard supergravity with Kähler potential

\[K = -3 \ln \{ \mathcal{T} + \bar{\mathcal{T}} + f (S, \bar{S}) \}\]

and superpotential

\[W = 6\mathcal{T}S.\]
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The dual model is standard supergravity coupled to

\[ K = -3M_P^2 \ln \left( 1 + \frac{T}{M_P} + \frac{\bar{T}}{M_P} - 2\frac{SS}{M_P^2} + \frac{\zeta}{9}\frac{S^2\bar{S}^2}{M_P^4} \right) \]

and

\[ W = 6mTS. \]

During inflation \( \langle S \rangle = \langle \text{Im } T \rangle = 0 \) are strongly stabilized.

The model becomes

\[ e^{-1}L = -\frac{M_P^2}{2}R - \frac{1}{2}\partial\varphi\partial\varphi - \frac{3}{2}m^2M_P^2 \left( 1 - e^{-\sqrt{\frac{2}{3}}\varphi/M_P} \right)^2. \]
Higher curvature supergravity offers for free a candidate for inflation.

Can higher curvature supergravity do more?
For Starobinsky inflation the $\zeta$ parameter

$$f(S, \bar{S}) = 1 - 2 \frac{S\bar{S}}{M_P^2} + \frac{\zeta}{9} \frac{S^2\bar{S}^2}{M_P^4}$$

is chosen to be sufficiently large

$$\zeta > 3.5 \quad \text{for} \quad m_S^2 > 0 \quad \text{during inflation}.$$ 

For this choice there is only a single Minkowski supersymmetric vacuum.

What happens for

$$\zeta < 3.5?$$
If we set $\zeta = 1$ we find new vacua with

$$m_{3/2}^2 \sim m^2, \quad \langle F \rangle \sim m M_P.$$
Higher curvature supergravity has the possibility to accommodate two different sectors.

- The inflationary sector: Starobinsky model of inflation. \( \zeta > 3.5 \)
- SUSY-breaking sector: Hindawi-Ovrut-Waldram supersymmetry breaking. \( \zeta = 1 \)
- Can we combine? Not these models.

Can higher curvature supergravity accommodate BOTH inflation and supersymmetry breaking?
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Conclusions
To find the standard embedding of the Starobinsky model to supergravity we have used specific and non-generic terms

\[ f(S, \bar{S}) = 1 - 2 \frac{S\bar{S}}{M_P^2} + \frac{\zeta}{9} \frac{S^2 \bar{S}^2}{M_P^4}. \]

In a generic setup there will be also \textit{R}-symmetry violating terms

\[ f(S, \bar{S}) = 1 + \gamma \frac{S}{M_P} + \gamma \frac{\bar{S}}{M_P} - 2 \frac{S\bar{S}}{M_P^2} + \frac{\zeta}{9} \frac{S^2 \bar{S}^2}{M_P^4} + \cdots \]

The origin of these models is still \textit{pure supergravitational}. 

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generalizing higher curvature supergravity
We find the following vacua

- Supersymmetric Minkowski vacuum: \( \langle S \rangle = \langle T \rangle = 0 \)
- Minkowski vacuum with broken supersymmetry: \( \langle |S| \rangle \sim M_P, \langle T \rangle \sim M_P \).
... and cosmic inflation! (compatible with PLANCK '13)

For large inflaton values the model becomes

\[ e^{-1} \mathcal{L} = -\frac{M_P^2}{2} R - \frac{1}{2} \partial \varphi \partial \varphi - \frac{3}{2} m^2 M_P^2 \left( 1 - (1 + 4s_*) e^{-\sqrt{\frac{2}{3}} \varphi / M_P} \right)^2 \]

where \( s_* \) is the value of ReS at the start of inflation.

Figure: A plot of the scalar potential for large values of the inflaton field. Due to large \( \zeta \) the additional scalars are strongly stabilized.
After slow roll the scalaron is driven towards the SUSY breaking vacuum.

These models give a gravitino mass: $m_{3/2}^2 \sim m^2$.

From Planck data: $m \sim 10^{-5} M_P$.

The mediation scenario will control the scale and form of the soft terms. (see for example Hindawi, Ovrut, Waldram ’96)
New DOF?

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Conclusions
Higher curvature supergravity is favored by the Planck data as a candidate for inflation.

In addition it has a rich vacuum structure.

R-violating terms make it possible to unify cosmic inflation and supersymmetry breaking with pure higher curvature supergravity.

Minimal description of inflation and SUSY breaking: does not invoke any additional sector. Both are manifestations of HD supergravity.
Thank you!