Supergravity models for inflation

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ERC Advanced Grant DaMeSyFla

Physics on the Riviera 2015
Sestri Levante, September 18

Talk based on

Gianguido Dall'Agata & FZ JHEP12 (2014) 172
[arXiv:1411.2605] + follow-up in slow progress

For an excellent recent review, broader than this talk:
S. Ferrara and A. Sagnotti, arXiv:1509.01500

Plan

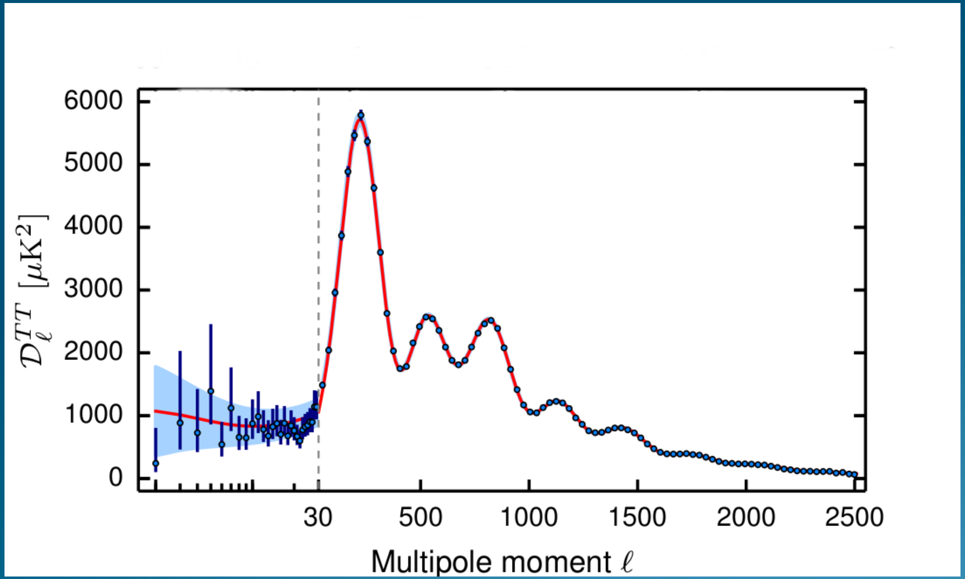
1. Introduction and motivations
2. Natural sgoldstino-less Minkowski vacua
3. Sgoldstino-less models of inflation
4. Our new sgoldstino-less models
5. Further comments and conclusions

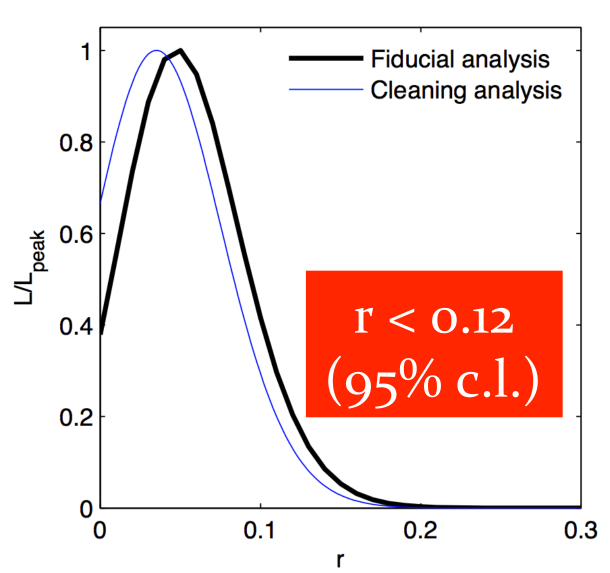
1.
Introduction and motivations

Recent impressive experimental progress, e.g.

Planck 2015 results arXiv:1502.02114

Joint analysis of BICEP2/KeckArray and Planck data arXiv:1502.00612





triggered renewed interest in supergravity as playground towards realistic & consistent models of (large-field) inflation

Problems

Hard and unsolved:

Cosmological constant ("Huge" hierarchy)

$$\langle V \rangle^{1/4}/M_P \sim 10^{-30}$$

"Large" and "Little" hierarchy after LHC-8

$$G_F^{-1/2}/M_P \sim 10^{-16} \qquad \frac{m^2_{W,Z,h}}{m^2_{sparticles,extra\,H}} \lesssim 10^{-2}$$

Easier and within reach:

1. Slow-roll conditions during inflation
2. Broken susy in flat space after inflation
3. Effective single-field inflation

The N=1 supergravity potential

Chiral multiplets $Z^I \sim (z^I, \psi^I, F^I)$

Kähler potential $K(Z, \overline{Z})$ superpotential $W(Z)$

$$V = V_F + V_G = F^I F_I - 3|W|^2 e^K$$

$$F_I = e^{K/2} D_I W \quad D_I W = W_I + W K_I$$

Supergravity vacua *in flat space*

broken susy

$$\langle F^I F_I \rangle = 3\langle |W|^2 e^K \rangle \neq 0$$

unbroken susy

$$\langle F^I F_I \rangle = \langle W \rangle = 0$$

Slow-roll conditions in supergravity

Inflaton chiral multiplet Φ   Inflaton field φ

$$\Phi = \phi + \sqrt{2}\theta\chi + \theta\theta F^{\Phi} \qquad \left(\phi = \frac{a + i\varphi}{\sqrt{2}}\right)$$

For canonical Einstein and inflaton kinetic term

$$\epsilon = \frac{1}{2}\left(\frac{V_{\varphi}}{V}\right)^2 \ll 1 \qquad \eta = \left|\frac{V_{\varphi\varphi}}{V}\right| \ll 1$$

e.g.

$$V = \frac{1}{2}M^2\varphi^2 \qquad V = V_0\left(1 - e^{-\sqrt{2/3}\varphi}\right)^2$$

($M \sim 10^{-5}$) [Linde 1983]   ($V_0 \sim 10^{-9}$) [dual of Starobinsky 1980]

Sugra η problem ($V \sim e^K$) solved by shift symmetry

$$K = K(\Phi + \overline{\Phi})$$

[Kawasaki-Yamaguchi-Yanagida 2000]

Broken susy in flat space after inflation

Realistic → susy broken at the end of inflation

$$\langle V \rangle \simeq 10^{-120} \qquad \langle F^I F_I \rangle > 10^{-60}$$

For our classical discussion, will require

$$\langle V \rangle = 0 \qquad \langle F^I F_I \rangle > 10^{-60}$$

A step forward w.r.t. many models with unbroken supersymmetry in Minkowski on the vacuum after the end of inflation

Questionable to treat susy breaking as a perturbation after the end of inflation

Better to deal with an explicit model

Effective single-field inflation

In the spectrum of a realistic sugra, the inflaton is not the only scalar in hidden + observable sector

Simplest case without large isocurvature fluct.s
"effective single-field inflation"
All extra scalars stabilized during inflation
by large inflaton-dependent mass terms

Potentially dangerous candidates:

- Second real scalar a in the inflaton multiplet Φ
- Sgoldstino® (complex scalar partner of goldstino)
- Also squarks + sleptons + Higgs bosons

®: Brignole-Feruglio-FZ, PLB 438 (1998) 89 [hep-ph/9805282]

2.

Natural sgoldstino-less Minkowski vacua with broken supersymmetry

Classical no-scale models

Minimal model with 1 chiral multiplet T

[Cremmer-Ferrara-Kounnas-Nanopoulos 1983]

$$K = -3\log(T+\overline{T}) \qquad W = W_0 \neq 0$$

$$K^T K_T = 3 \quad \Rightarrow \quad V = 0 \quad F^T F_T \neq 0$$

Classically vanishing vacuum energy, broken SUSY, massless complex scalar flat direction T $(T+\overline{T}>0)$

Alternative parameterization $Z = (2T-1)/(2T+1)$

$$K = -3\log(1-|Z|^2) \qquad W = W_0\,(1-Z)^3$$

Naturally expanded around self-dual point Z=0 of the SU(1,1)/U(1) manifold, corresponding to T=1/2

Coefficients of W expansion in powers of Z not fine-tuned but consequences of original T-independence

Sgoldstino-less models

Broken supersymetry ➔ chiral goldstino superfield

$$S = s + \sqrt{2}\theta\psi + \theta\theta F^S$$

sgoldstino↑ goldstino↑ ↑susy-breaking

Nonlinear realisation in goldstino sector

SUSY: impose quadratic constraint $S^2 = 0$

[Rocek 1978; Ivanov et al 1978; Casalbuoni et al 1989; Komargodski et al 2009]

Feasible also in SUGRA by Lagrange multiplier

[Antoniadis,Dudas,Ferrara,Sagnotti 2014; Ferrara,Kallosh,Linde 2014]

$$S^2 = 0 \;\; (F^S \neq 0) \;\Rightarrow\; s = \frac{\psi\psi}{2F^S} \;\Rightarrow\; s\psi = s^2 = 0$$

Two simple recipes:

- Compute V as usual, then set <s>=0 at the end
- Expand K & W around S=0, with S^2=0, rescale & Kahler transf ➔ canonical K, constant+linear W

A sgoldstino-less model with natural $\langle V \rangle_c=0$

Combine Z no-scale model and nilpotent Z ($Z^2=0$):

$$K = -3\log(1-|Z|^2) \to 3|Z|^2 \to |S|^2$$

$$W = W_0(1-Z)^3 \to W_0(1-3Z) \to W_0(1+\sqrt{3}\,S)$$

For $\langle s \rangle = 0$ as implied by the constraint

$$F^S F_S = 3|W_0|^2 \neq 0$$

As in no-scale model:
broken supersymmetry, vanishing vacuum energy

In contrast with no-scale model:

- Fixed gravitino mass $m^2_{3/2} = |W_0|^2$
- No flat directions, indeed no scalars at all

Adding unconstrained chiral multiplets

Add Φ^i (i=1,...,n) and take:

$$K = |S^2| + g(\Phi, \overline{\Phi})$$

Promote W_0 to an analytic function $f(\Phi)$

$$W = f(\Phi)(1 + \sqrt{3}S)$$

$<s> = 0$ ➔ $F^S F_S = 3|W|^2$

if $F^i F_i = 0$ admits solutions with $<f(\phi)> \neq 0$

then $V \geq 0$ and broken susy in Minkwoski

Notice:

$<F^S> \neq 0$ and $<F^i> = 0$ consistent with

S = nilpotent goldstino multiplet

3.

Sgoldstino-less models of inflation (with two chiral superfields)

FKL models [Ferrara-Kallosh-Linde arXiv:1408.4096, refs therein]

$$K = \frac{1}{2}(\Phi + \overline{\Phi})^2 + |S|^2 \quad W = Sf(\Phi)$$

<s> = 0 ➔ for all Φ during inflation

$$F^S = e^{a^2/2}\,\overline{f}(\overline{\phi}) \quad F^\Phi = 0 \quad W = 0$$

$$V = e^{a^2}|f(\phi)|^2$$

For suitable f (ϕ), a=0 during inflation

Large variety of potentials, but

$$\langle V \rangle = 0 \Rightarrow \langle f(\phi) \rangle = 0 \Rightarrow \langle F^S \rangle = \langle F^\Phi \rangle = \langle W \rangle = 0$$

Minkowski vacuum is supersymmetric

nilpotency condition becomes singular

KL models [Kallosh-Linde **arXiv:1408.5950]**

Susy-breaking by adding constant W_o

$$K = \frac{1}{2}(\Phi + \bar{\Phi})^2 + |S|^2 \quad W = S\, f(\Phi) + W_0\,.$$

If <ϕ>=0 & f(0)≠0 [➔f ‘ (0)=0] :

slow-roll inflationary potential generated

a=0 enforced by a large φ-dependent mass

$$F^{\phi} = e^{a^2/2}\sqrt{2}\,a\,\overline{W_0}$$

vanishing along a=0 inflationary trajectories

$$\langle V \rangle = |f(0)|^2 - 3|W_0|^2$$

Minkowski vacuum requires huge fine-tuning

Fine-tuned but self-consistent picture

ADFS models [Antoniadis-Dudas-Ferrara-Sagnotti arXiv:1403.3269]

The first to combine S (nilpotent) & Φ (inflaton)

$$K = -3\log(\Phi + \overline{\Phi} - |S|^2) \qquad W = W_0 + (f + M\,\Phi)\,S$$

Starobinsky potential for φ

Large φ-dependent mass for a during inflation

SU(2,1) no-scale properties <V>=0 thanks to $S^2=0$:

$$F^{\Phi}F_{\Phi} = 3e^{K}|W_0|^2 \qquad F^S F_S = \frac{|f + M\phi|^2}{3(\phi+\overline{\phi})^2}$$

Unbroken (broken) susy for $W_0=0$ ($W_0\neq 0$)

But <F^S>=0 singularity of nilpotency constraint

4.

Our new sgoldstino-less models

General structure

$$K = \frac{1}{2}(\Phi + \bar{\Phi})^2 + |S|^2 \quad W = f(\Phi)(1 + \sqrt{3}\, S)$$

with some mild requirements on f(Φ) [see paper]

As already discussed: <s> = 0 ➔ $F^S F_S = 3|W|^2 e^K$ ➔

$$V = F^{\Phi} F_{\Phi} = e^{a^2} |f'(\phi) + \sqrt{2} f(\phi) a|^2$$

Potential symmetric for a➔-a and φ➔φ

a rapidly driven to zero during inflation ➔

$$V_{inf} = \left| f' \left(\frac{i\,\varphi}{\sqrt{2}} \right) \right|^2$$

at the end of inflation $\langle \phi \rangle = 0$ and $\langle F^S F_S \rangle = 3|f(0)|^2$

Intreresting new features

- Inflaton potential controlled by $|f'|^2$ rather than by $|f|^2$ as in FKL/KL models ➔ can decouple the inflation and supersymmetry breaking scales

- Wide functional freedom in the choice of $V_{inf}(\varphi)$

$$V_{inf} = \mathcal{F}^2(\varphi)$$

(real analytic function)² reproduced by choosing

$$f(\Phi) = -i \int d\Phi \mathcal{F}\left(-i\sqrt{2}\Phi\right)$$

integration constant ↔ susy-breaking scale

Examples

Minimal quadratic potential

$$V_{inf} = \frac{M}{2}\varphi^2$$

$$f(\Phi) = \lambda - \frac{M}{2}\Phi^2 \quad (\lambda, M > 0)$$

Starobinsky potential, α-attractors [FKL+Porrati+Roest]

$$V_{inf} = V_0\left(1 - e^{-\sqrt{\frac{2}{3\alpha}}\varphi}\right)^2$$

$$f(\Phi) = \lambda - i\sqrt{V_0}\left(\Phi + i\frac{\sqrt{3\alpha}}{2}e^{i\frac{2}{\sqrt{3\alpha}}\Phi}\right)$$

5.

Further comments and conclusions

Further comments

- Inclusion of quarks/leptons Z^i straightforward
  can be easily frozen at $Z^i=0$ during inflation

- More delicate to include EW symmetry breaking
  with SM-like Higgs and no other light scalars

- Unitarity constraints OK throughout inflation:

$$E_q \sim V_{inf}^{1/2}(\varphi) < m_{3/2}(\varphi) \Rightarrow |f'(\phi)|^2 < |f(\phi)|$$

Conclusions

Built new supergravity models for inflation with

- All scalars ≠ inflaton frozen during inflation (large φ-dependent masses and $S^2=0$ constraint)
- Spontaneously broken susy with <V>=0 after the end of inflation (underlying classical geometry)
- Consistent use of the nilpotent multiplet S

  ($F^S \neq 0$ during and after inflation)

Among the challenging open problems:

consistent inclusion of SM-like Higgs at 125 GeV