Inflation from Supergravity with Gauged R-symmetry in de Sitter vacuum

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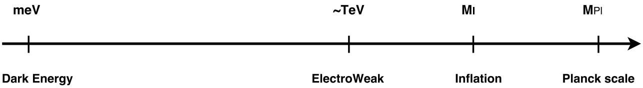
A fundamental theory of nature should describe both particle physics and cosmology, and contains very different scales:



Problem of scales:

- Incorporate Dark Energy
- Describe high energy (SUSY?) extension of the Standard Model
- Describe accelerated expansion phase of our universe

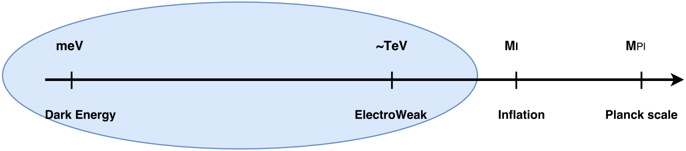
We propose a ($\mathcal{N} = 1$ SUGRA) model that:

- Connects the scale of inflation with the EW and SUSY breaking scales within the same effective field theory
- Allows for a (positive and tunably small) cosmological constant
- Admits a sparticle spectrum that evades experimental constraints
- Slow roll inflation within CMB constraints

[Antoniadis, Chatrabhuti, Isono, RK '16]

Outline:

- How to build a SUGRA theory
- Review of the model + sparticle spectrum
- Extension of this model to incorporate inflation


meV
~TeV
MI
MPl
Dark Energy
ElectroWeak
Inflation
Planck scale

Ingredients of $\mathcal{N} = 1$ SUSY (or SUGRA) theory:

- a Käler potential $K(z, \bar{z})$
- a superpotential $W(z)$
- a gauge kinetic function $f(z)$

$\mathcal{K}$, W, and f fully determine a $\mathcal{N} = 1$ supergravity theory (up to Chern-Simons terms).

The plan:

Define particle content and symmetries

Choose $\mathcal{K}$, W, f based on symmetry principles

Define parameter range where the scalar potential admits a tunably small and positive minimum

- one chiral multiplet $S = (s, \chi)$ with *gauged shift symmetry*

$$s \longrightarrow s - i\alpha c \tag{1}$$

- one gauge multiplet (λ, A_μ)

[Villadoro, Zwirner '05], [Antoniadis, RK '14], [Antoniadis, Ghilencea, RK '15], [Antoniadis, RK, '15]

- **Kähler potential**:

  Gauge invariance $\rightarrow \mathcal{K}(s+\bar{s})$

  String inspired choice

$$\mathcal{K}(s,\bar{s}) = -p\log(s+\bar{s}) \tag{2}$$

  s can be the string dilaton ($s = 1/g^2 + ia$) or compactification modulus.

- Most general **Superpotential**:

$$W = ae^{bs} \tag{3}$$

Under shift $W \rightarrow We^{-ibc\alpha}$: R-symmetry

- Most general **Gauge kinetic function**:

$$f(s) = \gamma + \beta s \tag{4}$$

Scalar potential: ($\phi = s + \bar{s}$)

$$\mathcal{V} = \mathcal{V}_F + \mathcal{V}_D, \tag{5}$$

$$\mathcal{V}_F = \frac{\kappa^{-4}|a|^2}{\phi^p} e^{b\phi} \left(-3 + \frac{1}{p} (b\phi - p)^2 \right),$$
$$\mathcal{V}_D = \frac{\kappa^{-4} c^2}{\beta\phi + 2\gamma} \left(b - \frac{p}{\phi} \right)^2. \tag{6}$$

For $b < 0$ and $p < 3$, a *de Sitter* minimum can be found

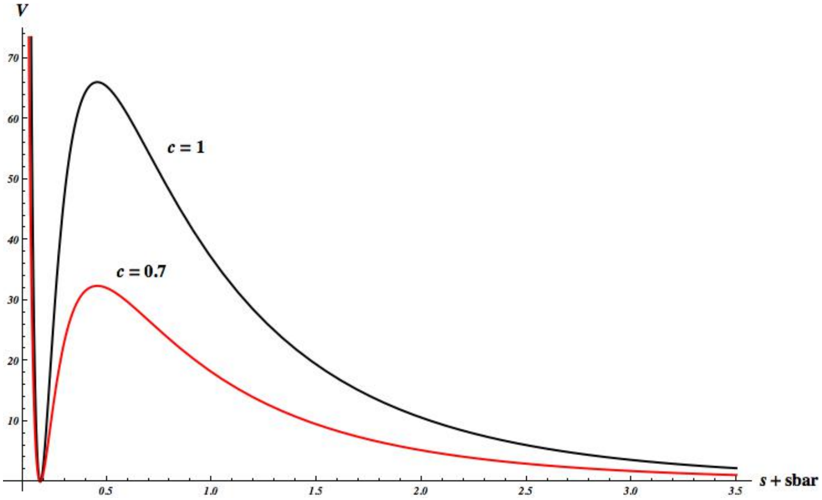
Example: $p = 2$, $\gamma = 0$, $\beta = 1$

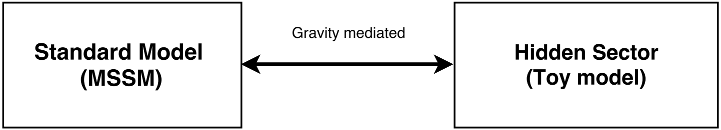
$\mathcal{V}(\phi_{\text{min}}) = 0$, and $d\mathcal{V}(\phi_{\text{min}})/d\phi = 0$ gives

$$b\phi_{\text{min}} = l_0 \approx -0.183268, \tag{7}$$

and

$$\frac{a^2}{bc} = \mathcal{A}(l_0) \approx -50.66. \tag{8}$$


V
70
60
50
40
30
20
10
c = 1
c = 0.7
0.5
1.0
1.5
2.0
2.5
3.0
3.5
s + sbar



Results in distinctive low energy spectrum:

- Very light gauginos
- Mostly Bino-like LSP
- Very heavy squarks $\sim O(10\text{ TeV})$
- Light stop (~ 2 TeV)

shift symmetry can be identified with $U(1)_{B-L}$

[Antoniadis, RK, '15]

In this model:

- Real part of s gets VEV and breaks SUSY
- Im(s) is eaten (Stuckelberg) by gauge boson, which becomes massive.
- Linear combination of chiral fermion and gaugino is eaten (SuperHiggs) by gravitino, other one acquires a mass by SUSY breaking.
- **Question:** Can Re(s) be the inflaton?

The kinetic terms are

$$\mathcal{L}_s/e = -g_{s\bar{s}}\partial_\mu s \partial^\mu \bar{s} = -\frac{p\kappa^{-2}}{4}\frac{1}{\phi^2}\partial_\mu\phi\partial^\mu\phi. \tag{9}$$

The canonically normalized field χ

$$\chi = \kappa^{-1}\sqrt{\frac{p}{2}}\log\phi \tag{10}$$

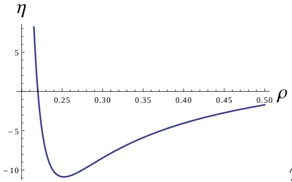
Slow roll parameters

$$\epsilon = \frac{1}{2\kappa^2}\left(\frac{dV/d\chi}{V}\right)^2 = \frac{1}{2\kappa^2}\left[\frac{1}{V}\frac{dV}{d\phi}\left(\frac{d\chi}{d\phi}\right)^{-1}\right]^2,$$

$$\eta = \frac{1}{\kappa^2}\frac{V''(\chi)}{V} = \frac{1}{\kappa^2}\frac{1}{V}\left[\frac{d^2V}{d\phi^2}\left(\frac{d\chi}{d\phi}\right)^{-2} - \frac{dV}{d\phi}\frac{d^2\chi}{d\phi^2}\left(\frac{d\chi}{d\phi}\right)^{-3}\right]$$

η is only a function of $\rho = -b\phi$

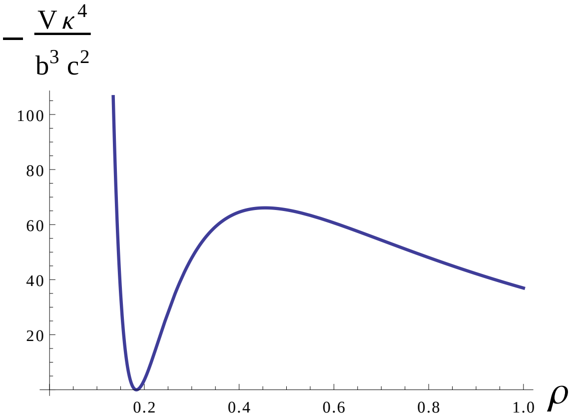
$$\eta = \frac{2e^{\rho}\left(3\rho^2 + 32\rho + 60\right) - \mathcal{A}(l_0)\rho\left(\rho^4 + 5\rho^3 + 10\rho^2 + 2\rho - 16\right)}{2e^{\rho}(\rho+2)^2 - \mathcal{A}(l_0)\rho\left(\rho^2 + 4\rho - 2\right)}$$



$\eta << 1$ cannot be satisfied

The plateau of the scalar potential is not flat enough

$$\frac{\kappa^4 \mathcal{V}(\rho)}{b^3 c^2} = \frac{e^{-\rho}\left(\mathcal{A}(l_0)\rho\left(\rho^2 + 4\rho - 2\right) - 2e^{\rho}(\rho+2)^2\right)}{2\rho^3}, \qquad (11)$$



Introduce corrections to the Kähler potential

$$\mathcal{K} = -p \log \left(s + \bar{s} + \frac{\xi}{b} F(s + \bar{s}) \right)$$
$$W = a e^{bs}, \quad f(s) = \gamma + \beta s \tag{12}$$

Possible corrections (string inspired, $\mathrm{Re}(s) \sim 1/g_s$)

- Perturbative $F \sim (s + \bar{s})^{-n}, \quad n \geq 0$
- Non-Perturbative
  - D-brane instantons $F \sim e^{-\delta(s+\bar{s})}, \quad \delta > 0$
  - NS5-brane instantons $F \sim e^{-\delta(s+\bar{s})^2}, \quad \delta > 0$

Only the last type of correction allows for a plateau

Correction to Kähler potential

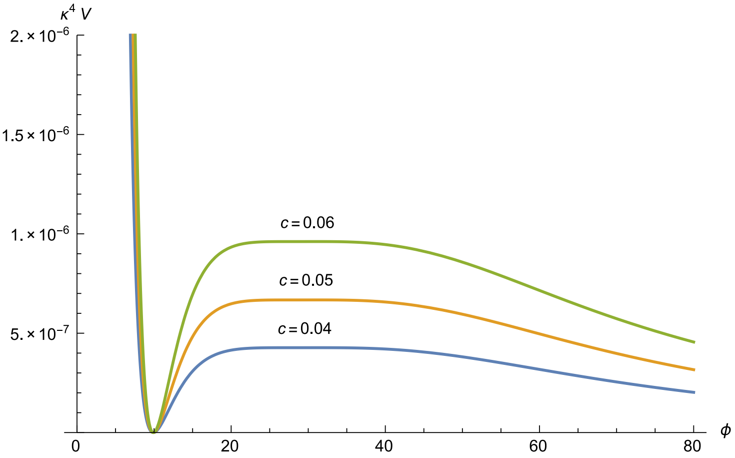
$$F(\phi) = \exp(\alpha b^2 \phi^2), \quad b < 0, \alpha < 0 \tag{13}$$

Scalar potential

$$\mathcal{V} = \mathcal{V}_F + \mathcal{V}_D \tag{14}$$

$$\mathcal{V}_D = \frac{\kappa^{-4} b^3 c^2}{b\phi} \left[\frac{b\phi - 2 + \xi e^{\alpha b^2 \phi^2}(1 - 4\alpha b\phi)}{b\phi + \xi e^{\alpha b^2 \phi^2}} \right]^2$$

$$\mathcal{V}_F = -\frac{\kappa^{-4} |a|^2 b^2 e^{b\phi}}{2\left(\xi e^{\alpha b^2 \phi^2} + b\phi\right)^2} \left[\frac{\left(b\phi + \xi e^{\alpha b^2 \phi^2}(1 - 4\alpha b\phi) - 2\right)^2}{2\alpha\xi e^{\alpha b^2 \phi^2}\left(2\alpha b^3 \phi^3 + \xi e^{\alpha b^2 \phi^2} - b\phi\right) - 1} + 6 \right]$$



$\kappa^4 V$
$2.\times 10^{-6}$
1.5×10^{-6}
$1.\times 10^{-6}$
$5.\times 10^{-7}$
0
20
40
60
80
ϕ
$c = 0.06$
$c = 0.05$
$c = 0.04$

Inflation starts at ϕ_* near the maximum, and ends when $|\eta| = 1$
Number of e-folds

$$N = \kappa^2 \int_{\chi_{end}}^{\chi_{int}} \frac{\mathcal{V}}{\partial_\chi \mathcal{V}} d\chi = \kappa^2 \int_{\phi_{end}}^{\phi_{int}} \frac{\mathcal{V}}{\partial_\phi \mathcal{V}} \left(\frac{d\chi}{d\phi} \right)^2 d\phi. \tag{15}$$

Predictions for the power spectrum of perturbations of the CMB

$$\begin{aligned} \text{Amplitude of density fluctuations} \quad A_s &= \frac{\kappa^4 \mathcal{V}_*}{24\pi^2 \epsilon_*}, & (16) \\ \text{Spectral index} \quad n_s &= 1 + 2\eta_* - 6\epsilon_*, & (17) \\ \text{Tensor-to-scalar ratio} \quad r &= 16\epsilon_*, & (18) \end{aligned}$$

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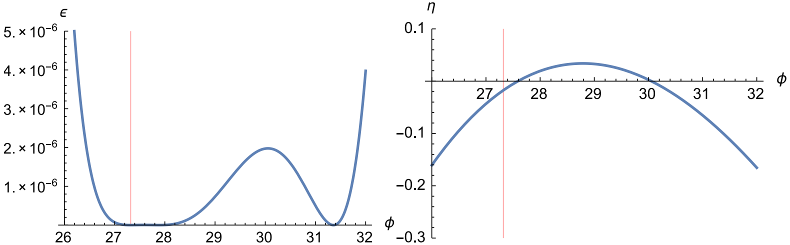
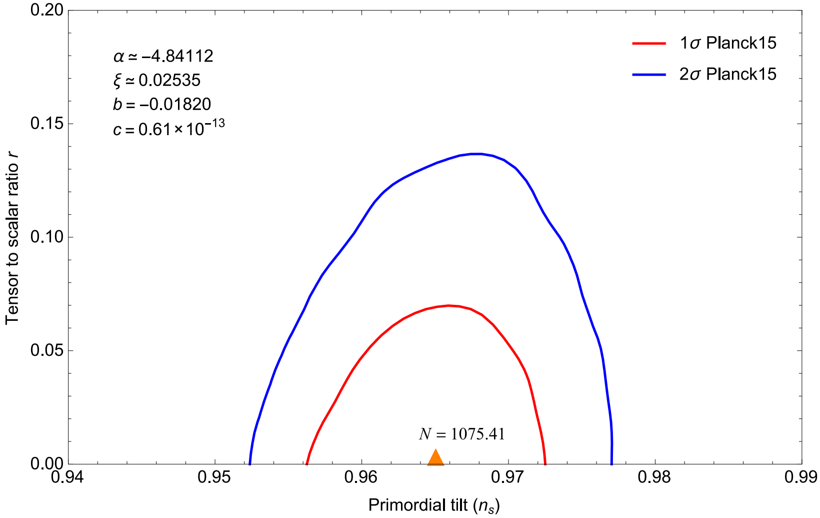
\end{aligned}$$

Numerical analysis: fits Planck '15, and keeps the SM minimum with an infinitesimal cosmological constant by fine-tuning the parameters of the model

Example For $p = 2$, $\phi_* = 27.32$, $\xi = 0.025$, $\alpha = -4.8$, $b = -0.018$, $c = 0.61 \times 10^{-13}$



N	n_s	r	A_s
1075.41	0.965	2.969×10^{-23}	2.259×10^{-9}



$\alpha \simeq -4.84112$
$\xi \simeq 0.02535$
$b = -0.01820$
$c = 0.61 \times 10^{-13}$
1σ Planck15
2σ Planck15
$N = 1075.41$
0.20
0.15
0.10
0.05
0.00
0.94
0.95
0.96
0.97
0.98
0.99
Tensor to scalar ratio r
Primordial tilt (n_s)

Conclusions and ideas:

- The inflaton is identified with the scalar partner of the Goldstino
- A cancellation between F-term and D-term allows for a tunably small cosmological constant
- Distinguishable low-energy sparticle spectrum
- A correction to the Kähler potential (maintains de SM vacuum and) allows for slow roll consistent with CMB
- During inflation $m^*_{3/2} < H_*$, which can lead to possible non-gaussianities and E-polarisation effects in CMB

BACKUP SLIDES

Kähler transformations: A supergravity theory (with $W(z) \neq 0$) can be written in terms of

$$\mathcal{G} = K + \log(W\bar{W}). \tag{19}$$

- $\mathcal{G}$ should be gauge invariant.
- $\mathcal{G}$ is invariant under Kähler transformations:

$$\begin{aligned} K(z,\bar{z}) &\longrightarrow K(z,\bar{z}) + J(z) + \bar{J}(\bar{z}) \\ W(z) &\longrightarrow We^{-J(z)} \end{aligned}$$

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Conclusion: K and W do not need to be gauge invariant. A gauge transformation can leave a Kähler transformation.

R-symmetry Gauge transformation α

$$K(z,\bar{z}) \longrightarrow K(z,\bar{z}) + \alpha r(z) + \alpha \bar{r}(\bar{z})$$
$$W(z) \longrightarrow W e^{-r(z)\alpha}$$

Kähler transformation: The model

$$K = -\log(s + \bar{s}),$$
$$W = ae^{bs} \tag{20}$$

is classically equivalent to

$$K = -\log(s + \bar{s}) + b(s + \bar{s}),$$
$$W = a \tag{21}$$

Avoid R-charges and anomalies $\longrightarrow$ take second representation.