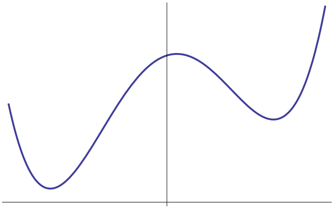
Dynamical D-term supersymmetry breaking

in particle physics and cosmology

arxiv 1410.4641



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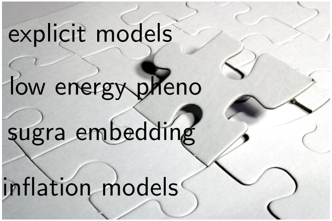
Motivation

Two roads to spontaneous supersymmetry breaking:

$\langle F \rangle \neq 0$



O'Raifeartaigh models

$\langle D \rangle \neq 0$

sugra embedding??

D-term inflation:
good fit to data

cosmic string problem?

Fayet Iliopoulos (FI) mechanism

This talk: D-terms in supergravity and their cosmology

The infamous D-term problems

D-term supersymmetry breaking in ...

- global supersymmetry: simple [Fayet, Illiopoulos '74]

  $\mathcal{L}_{\mathsf{FI}} = -g\,\xi\,D = -g\,\xi \int d^4\theta\,V, \quad \xi = \text{const.}$

  $V_D = \frac{1}{2}D^2 = \frac{1}{2}g^2(q_i|\phi_i|^2 - \xi)^2$

- supergravity: very hard, global symmetries render theory inconsistent

  [Komargodski, Seiberg '09/'10; Dienes, Thomas '10, Catino, Villadoro, Zwirner '12, ...]

- possible way out: field-dependent 'FI-term' ?
  $g\,\xi\,V \to f_{\mathsf{GS}}(V + \Phi + \Phi^\dagger)$ [Green, Schwarz '84]
  but stabilize modulus $\Phi \Rightarrow \xi \sim M_P^2$

see also [Dumitrescu, Komargodski, Sudano '10, Catino, Villadoro, Zwirner '11]

This talk: Dynamical 'FI-term' generation in supergravity can overcome all of these problems.

Dynamical supersymmetry breaking

based on strong $SP(N_c)$ gauge group with $N_f = N_c + 1$ flavours.
minimal example: $SP(1) \simeq SU(2)$ [Izawa, Yanagida '96, Intriligator, Thomas '96].

- field content: 4 'quarks' $Q \overset{\Lambda}{\mapsto}$ 6 'mesons' M; 6 singlets Z
- deformed moduli constraint

$$Pf(M) = M_1 M_2 - M_3 M_4 + M_5 M_6 = \Lambda^2 \ , \ [Pf(M)]^2 = \det(M)$$

- perturbative superpotential $W = \lambda_i \Lambda M_i Z_i$

$\Rightarrow$ Yukawas break flavour symmetry to U(1), take all $\lambda_i \neq 0$

$\Rightarrow \langle M_i \rangle \neq 0 \to \langle F_{Z_i} \rangle \neq 0 \Rightarrow$ F-term susy breaking

scale Λ via dimensional transmutation:

$$\Lambda = M_P \exp\left(- \frac{8\pi^2}{b\, g_s(M_P)} \right)$$

e.g. $g_s(M_P) = 1...4\pi \quad \to \Lambda = 10^{10}..10^{18}$ GeV

supersymmetry breaking by strong dynamics at scale Λ

Dynamical 'FI-term'

Weakly gauge a $U(1)$ subgroup of the flavour symmetry , $g \ll \lambda_i$

fields	Q_1	Q_2	Q_3	Q_4	Z_a^0	Z_+	Z_-
	$\overbrace{\quad\quad}^{M_+}$ (pair $Q_1 Q_2$)		$\overbrace{\quad\quad}^{M_-}$ (pair $Q_3 Q_4$)				
$U(1)$	$+1/2$	$+1/2$	$-1/2$	$-1/2$	0	$+1$	-1

D-term potential:

$$V_D = \frac{1}{2} g^2 (|M_+|^2 - |M_-|^2 + \dots)^2$$

with $\langle M_\pm \rangle^2 \simeq \frac{\lambda_\mp}{\lambda_\pm} \Lambda^2$ (and if all other charged fields stabilized at zero):

$$\xi = \Lambda^2 \left(\frac{\lambda_+}{\lambda_-} - \frac{\lambda_-}{\lambda_+} \right) (1 - \mathcal{O}(g^2))$$

Generates effective FI-term at dynamical scale Λ

A modulus problem?

neutral fields: $\lambda_0 \gg \lambda_\pm \to \langle Z_a^0 \rangle = 0 = \langle M_a^0 \rangle$

charged mesons in unitary gauge: $M_\pm = (\langle M_\pm \rangle + M) e^{\pm S}$

- deformed moduli constraint eliminates M: $M_- = \Lambda^2 / M_+$
- Goldstone multiplet S renders $U(1)$ vector multiplet massive

$$\begin{aligned} K &= M_+^\dagger e^{2gV} M_+ + M_-^\dagger e^{-2gV} M_- \\ &= K_0 + 2g \underbrace{\left(\langle |M_+|^2 \rangle - \langle |M_-|^2 \rangle \right)}_{-\xi} \left[V + (S + S^\dagger)/(2g) \right] + \ldots \end{aligned}$$

charged singlets $X = \frac{1}{\sqrt{2}}(Z_+ + Z_-)$, $Y = \frac{1}{\sqrt{2}}(Z_+ - Z_-)$

- $\langle Y \rangle = 0$ (Dirac mass term with S)
- Goldstino multiplet X. Pseudo modulus stabilized at one-loop.

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$$W = \mu^2 X - mSY + \frac{m^2}{2\mu^2} S^2 X + \mathcal{O}(S^3),$$

$$m \sim \lambda\Lambda, \quad \mu^4 = 2\lambda_+ \lambda_- \Lambda^4$$

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- 'modulus' S stabilized through F-terms.
- effective FI-term for $m_A \sim g\Lambda \ll E \ll m_S \sim \Lambda$
- supersymmetry breaking:

$$\langle F \rangle \sim \Lambda^2 > \langle D \rangle \sim g^2 \Lambda^2, \quad m_{3/2} \gtrsim \Lambda^2 / M_P$$

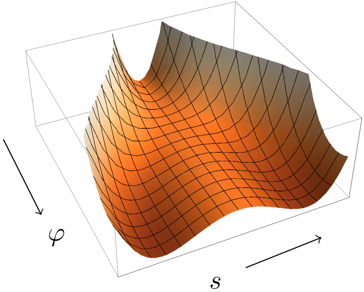
Applications in Cosmology and Particle Physics

D-term hybrid inflation: [Binetruy, Dvali '96; Halyo '96]

- $U(1)$ gauge symmetry with Fayet-Iliopoulos term ξ
- $W = \kappa \, \phi \, S_+ S_- \,,$

- ξ: vacuum energy
- ϕ: inflaton φ, tree-level flat
- $S_\pm$: waterfall field, $|S_+|$ destabilize at

$$\varphi_c = \frac{g}{\kappa}\sqrt{2\xi}$$



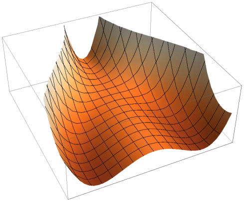
Main problems: FI-term inconsistent? Cosmic strings? n_s too large?

Applications in Cosmology and Particle Physics

Dynamical D-terms for hybrid inflation

- here: cosmic string problem is avoided!
- F-term susy breaking in Minkowski vacuum after inflation
- Starobinsky limit and $m^2\phi^2$ limit

[Buchmüller, VD, Kamada '13], [Buchmüller, VD, Schmitz '14]



Outlook

- sparticle spectrum..
- $U(1)_{\mathsf{FI}} \leftrightarrow G_{\mathsf{GUT}}$

opens new roads for model building in particle physics and cosmology

Conclusion

- dynamical susy breaking $\rightarrow$ dynamical D-term generation
- effective FI-term below dynamical scale Λ, $\Lambda \sim \Lambda_{\mathsf{GUT}}$ possible
- gauge invariant in sugra, no moduli stabilization necessary
- F- and D-terms play a role: $\langle F \rangle > \langle D \rangle$
- one possible application: D-term inflation

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Thank you!

Questions?