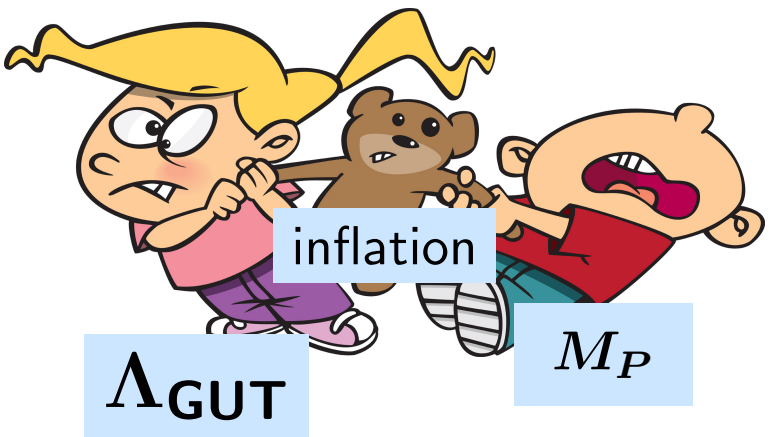
Towards chaotic inflation in SUSY GUTs

The rebirth of D-term inflation

arxiv[hep-ph] 1406.6300, 1410.xxxx



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and T. Yanagida

Motivation

Data: $r \sim 0.1\,(?) \quad \rightarrow \quad V_0^{1/4} \sim 10^{16}$ GeV $\sim \Lambda_{\text{GUT}}$

$\rightarrow$ How can we link the scale of inflation to a scale of particle physics?

Theory: supersymmetric D-term hybrid inflation

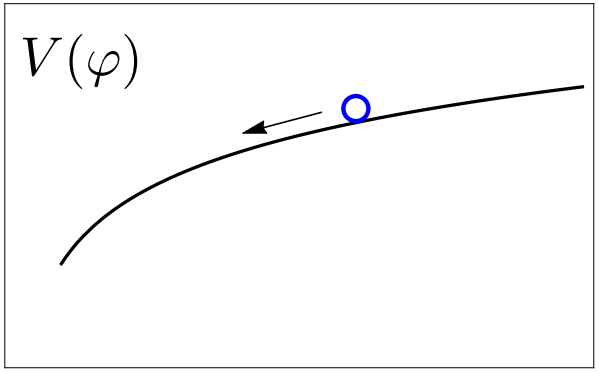
- consistent in supergravity
- no cosmic string problem
- new regime with very different predictions

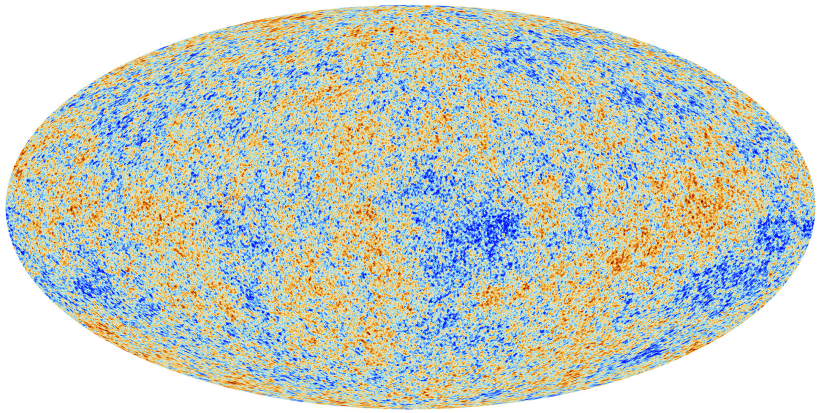
Outline

- small- and large-field models of inflation
- the chaotic regime of D-term hybrid inflation
- dynamical generation of a Fayet-Illiopoulos term
- conclusion and outlook

Some observations about slow-roll inflation

The basics:





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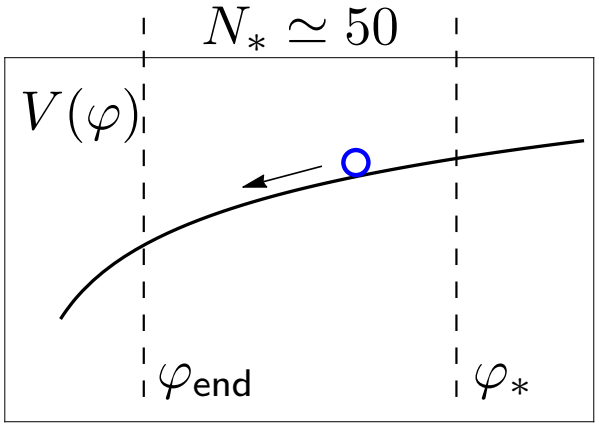

$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2, \quad \eta = \frac{V''}{V}$$

$$A_s = \frac{V_*}{24\pi^2\epsilon_*}, \quad n_s = 1 - 6\epsilon_* + 2\eta_*, \quad r = 16\epsilon_*$$

$$\Delta\varphi \gtrsim 5\, M_{\text{P}}\, \frac{N}{50}\sqrt{\frac{r}{0.1}}$$

[Lyth '96]

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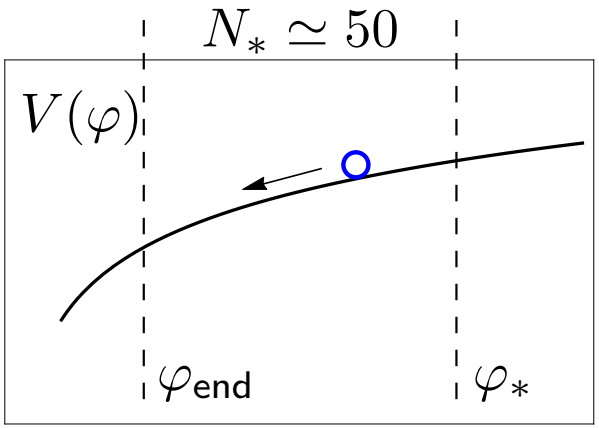

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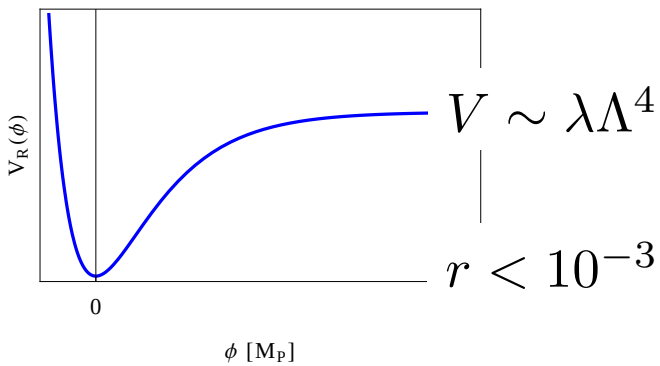
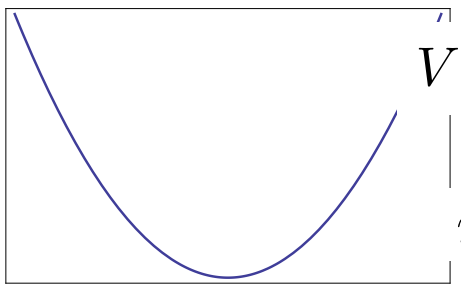
Small-field models:



$$V \sim \lambda\Lambda^4$$

$$r < 10^{-3}$$

Large-field models:



$$V \sim m^2\varphi^2$$

$$r \sim 0.1$$

Can large-field models be connected to grand unification?

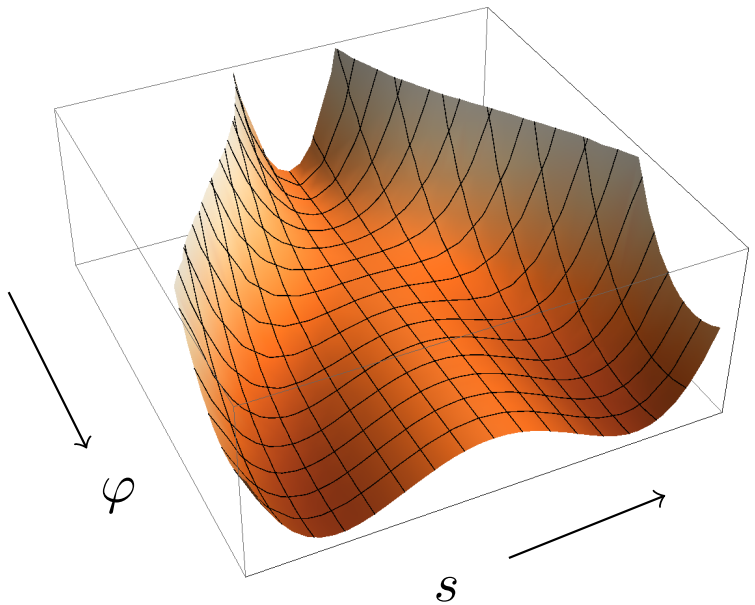
D-term hybrid inflation in a nutshell

A supersimple model: [Binetruy, Dvali '96; Halyo '96] [Kawasaki, Yamaguchi, Yanagida '00]

- $U(1)$ gauge symmetry with Fayet-Iliopoulos term ξ
- $W = \lambda\phi S_+ S_- \,, \qquad K = \frac{1}{2}(\phi+\bar{\phi})^2 + S_+\bar{S}_+ + S_-\bar{S}_-$

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

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



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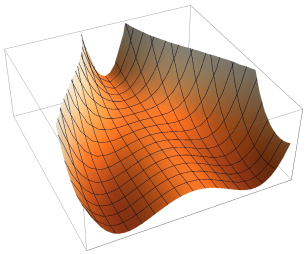

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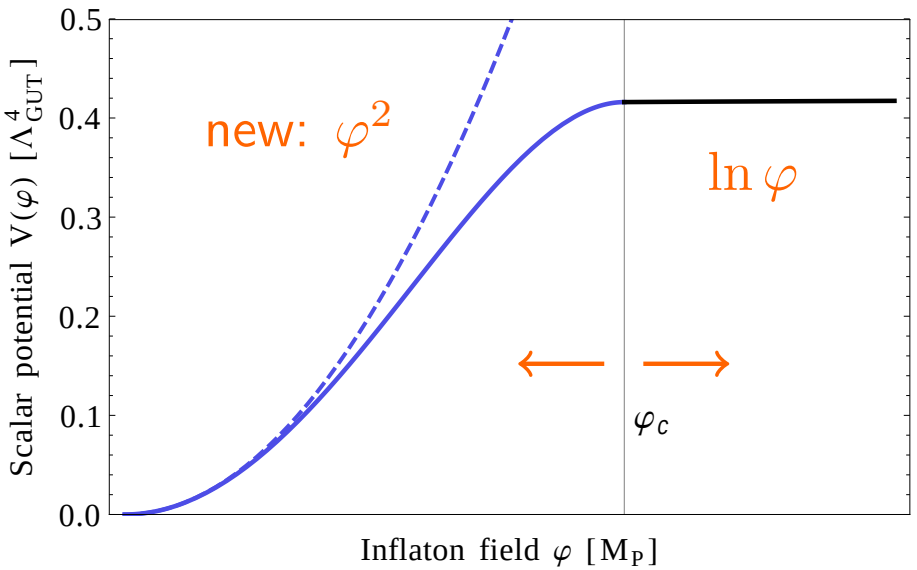


$\lambda \gg g$: D-term hybrid inflation. $\lambda \ll g$: new regime

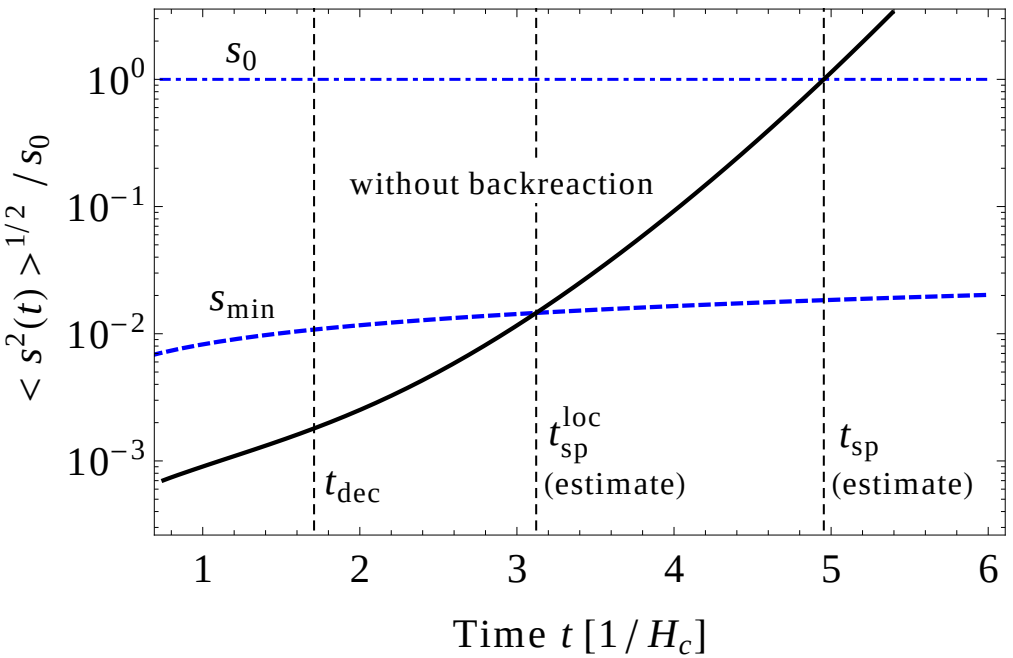
Quantum mechanics: tachyonic growth

Close to the critical point:

$$\varphi(t) \simeq \varphi_c + \dot{\varphi}_c t \quad \rightarrow \quad V(s;t) \simeq \frac{1}{2} g^2 \xi^2 - \frac{1}{2} D^3 t s^2 + \mathcal{O}(t^2, s^4)$$

$\rightarrow$ tachyonic growth of s_k for small k: [Asaka, Buchmüller, Covi '01]

$$\ddot{s_k} + \left(k^2 e^{-2Ht} - \frac{9}{4} H^2 \ - D^3 t \right) s_k = 0$$

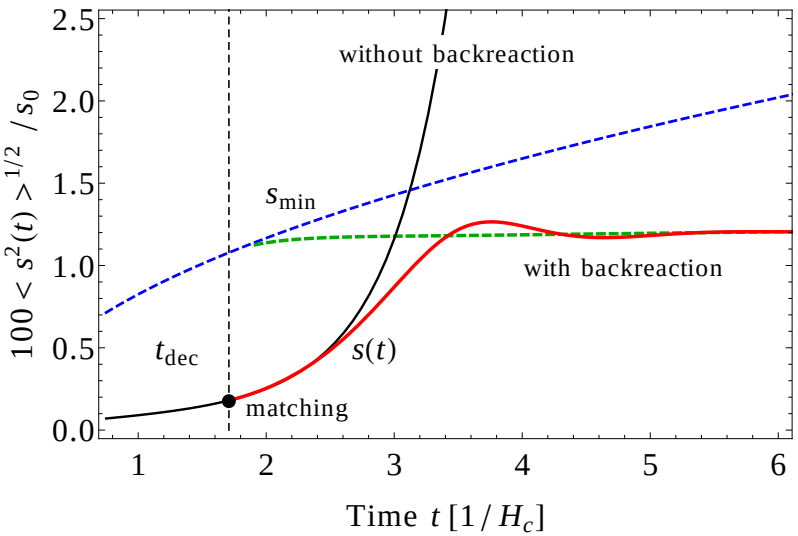


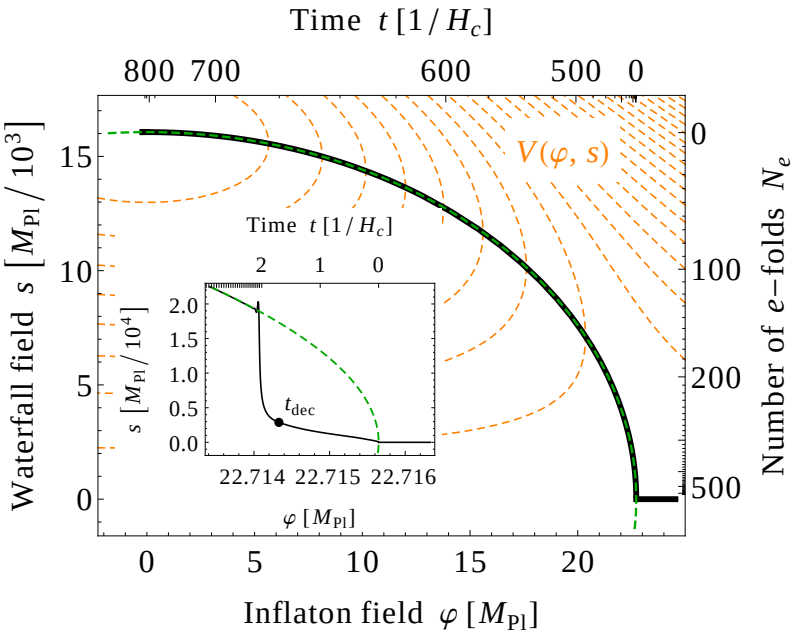
- spinodal time
  $\langle s^2(t) \rangle = s_{\rm vacuum}$
- decoherence time
  $|s_k(t)\pi_{sk}(t)| \gg \hbar$
  $\dot{s}/H > H/(2\pi)$

Classical evolution: backreaction

Backreaction sets in once we overshoot the minimum:

$$\ddot{\varphi} + 3H\dot{\varphi} + \frac{1}{2}\lambda^2 s^2 \varphi = 0\,, \quad \ddot{s} + 3H\dot{s} - \left(g^2\xi - \frac{\lambda^2}{2}\varphi^2\right) s + \frac{g^2}{2}s^3 = 0$$





inflaton field tracks *local* minimum. λ/g sets ratio of semi-axes.

Implications for cosmology and particle physics

After the critical point: $V(\varphi, s_{\min}(\varphi)) = \frac{1}{2}\lambda^2\xi\,\varphi^2\left(1-\frac{1}{2}\frac{\varphi^2}{\varphi_c^2}\right)$
with $\varphi_c \propto g/\lambda > M_P$. $\rightarrow$ $m^2\varphi^2$ inflation + small correction!

predictions:

$$A_s \simeq \frac{\lambda^4\varphi_*^4\varphi_c^2}{192\pi^2 g^2}\left(1+\frac{1}{2}\frac{\varphi_*^2}{\varphi_c^2}\right), \quad n_s \simeq 1-\frac{8}{\varphi_*^2}\left(1-\frac{1}{4}\frac{\varphi_*^2}{\varphi_c^2}\right), \quad r \simeq \frac{32}{\varphi_*^2}\left(1-\frac{\varphi_*^2}{\varphi_c^2}\right).$$

e.g. $g^2 = \frac{1}{2}$, $\lambda = 5\cdot 10^{-4}$: $\varphi_* = 14.5\,M_{\rm P}$, $n_s = 0.963$, $r = 0.083$

constraints:

sufficient inflation after φ_c: $\lambda \lesssim 10^{-3}$, $\sqrt{\xi} \gtrsim 2\times 10^{16}$ GeV

validity of this formalism: $\lambda \gtrsim 10^{-4}$, $\sqrt{\xi} \lesssim 2\times 10^{17}$ GeV

no cosmic string problem!

chaotic inflation with slightly reduced r. GUT scale FI-term.

Final remarks on D-term 'hybrid' inflation

- We retrieve chaotic inflation from D-term hybrid inflation
- Inflation is linked to the decay of a GUT-scale false vacuum
- Interplay of quantum and classical dynamics
- If BICEP is dust, 'usual' D-term hybrid inflation is still viable for λ/g large enough (but tension with cosmic string bound)

  [Buchmüller, VD, Kamada '13]

- Supergravity embedding of FI-term tricky

  [Komargodski, Seibergy '09 and '10; Dienes, Thomas '10]

Dynamical supersymmetry breaking

based on strong $SP(1) \simeq SU(2)$ gauge group [Izawa, Yanagida '96, Intriligator, Thomas '96]

- field content below Λ: 4 'quarks' Q, 6 'mesons' M, 6 singlets Z
- perturbative superpotential $W = \lambda_i M_i Z_i$
- deformed moduli constraint

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

$\Rightarrow \langle M_i \rangle \neq 0 \rightarrow \langle F_{Z_i} \rangle \neq 0 \Rightarrow$ susy breaking

scale Λ via dimensional transmutation:

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

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

supersymmetry breaking by strong dynamics at scale Λ

Dynamical 'FI-term'

Gauge a $U(1)$ subgroup of the flavour symmetry

work in progress w K. Schmitz and T. Yanagida

fields	$\overbrace{Q_1 \quad Q_2}^{M_+}$		$\overbrace{Q_3 \quad Q_4}^{M_-}$		Z_a^0	Z_+	Z_-
$U(1)$	$+1/2$	$+1/2$	$-1/2$	$-1/2$	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 all other fields stabilized at zero):

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

Effective GUT-scale FI-term generated

Conclusion and Outlook

Realization of D-term hybrid inflation with dynamical FI-term

- consistent in supergravity
- no cosmic string problem
- GUT scale arises naturally
- chaotic regime of D-term inflation with sizeable r

Outlook

- Further applications of dynamical FI-term
- $U(1)_{\mathsf{FI}} \leftrightarrow G_{\mathsf{GUT}}$?
- more results on the search of primordial B-modes coming soon !

Thank you!

Questions?