Confronting SUSY hybrid inflation with the CMB

Marieke Postma

(Nikhef, Amsterdam)

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R. Jeannerot & MP, JCAP 0607:012,2006, JHEP 0505:071,2005

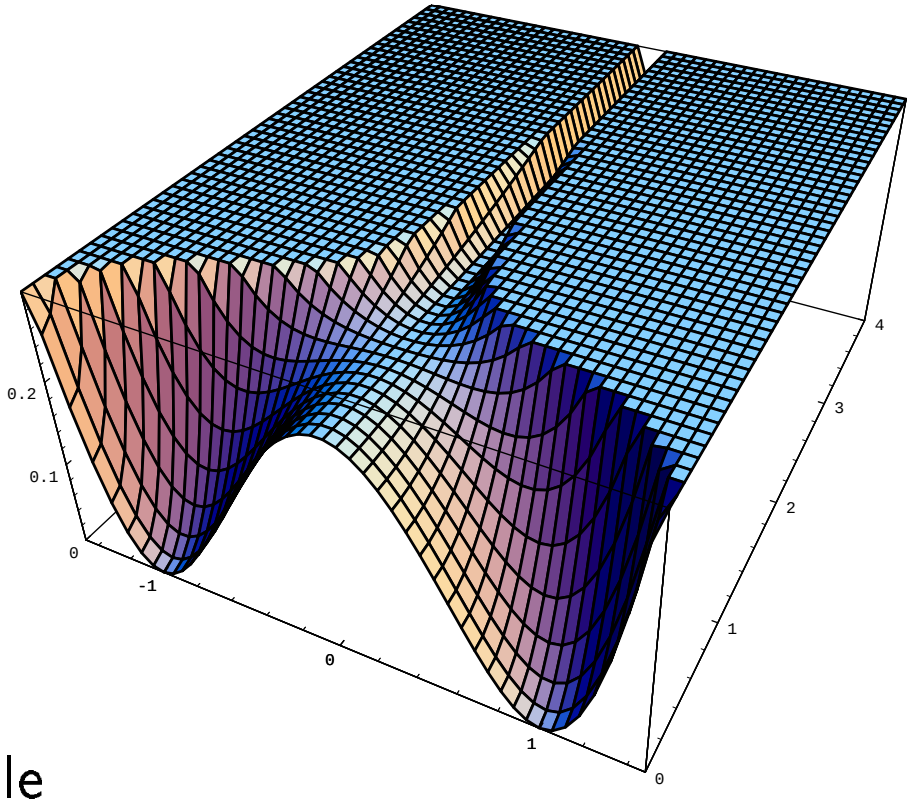
Plan of the talk

- Overview
  - F & D-term inflation
  - cosmic strings
- F-term inflation
  - density perturbations
  - parameter space
- D-term inflation
  - density perturbations
  - parameter space
- Conclusions

Hybrid inflation & cosmic strings

Hybrid inflation

Linde '93



Nice features:

- $S < m_{\rm p}$ during inflation
- $\mathcal{O}(1)$ couplings & GUT scale
- graceful exit
- cosmic strings
- arises in SUSY & string theory

F-term vs. D-term inflation

Dvali, Shafi & Schaefer '94; Binetruy, Dvali '96

$$V = \sum |\partial W/\partial \phi_i|^2 + \tfrac{1}{2} D^2 \quad \text{with} \quad W = \kappa S(\phi\bar{\phi} - M^2)$$

$$D = g(|\phi|^2 - |\bar{\phi}|^2 - \xi)$$

F-term

$\xi = 0 \quad \Rightarrow \quad V_0 = \kappa^2 M^4$

$m_\pm^2 = \kappa^2(S^2 \pm M^2)$

η-problem

$G \to H$
GUT theories
strings non-BPS

D-term

$M = 0 \quad \Rightarrow \quad V_0 = \tfrac{1}{2} g^2 \xi^2$

$m_\pm^2 = \kappa^2 S^2 \pm g^2 \xi$

no η-problem

$U(1) \to I$
brane inflation
strings BPS

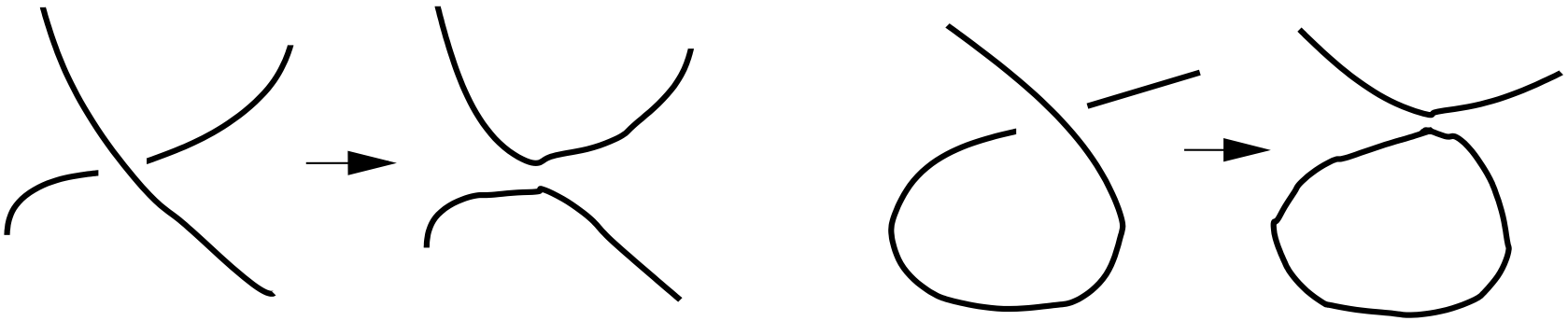
Topological defects

- domain walls: discrete symmetry, too heavy 
- monopoles: GUT symmetry, no annihilation 
- strings: e.g. $U(1)$

Topological defects

- domain walls: discrete symmetry, too heavy ✗
- monopoles: GUT symmetry, no annihilation ✗
- strings: e.g. $U(1)$ ✓

Strings have energy loss mechanism!



Topological defects

- domain walls: discrete symmetry, too heavy ✗
- monopoles: GUT symmetry, no annihilation ✗
- strings: e.g. $U(1)$ ✓

Strings OK

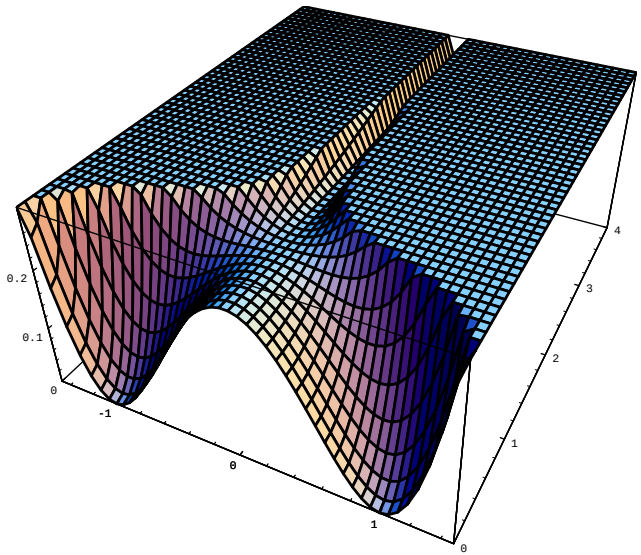
D-term:
- $U(1)$

F-term:
- SM + $U(1)_{B-L}$
- $\mathrm{G} \overset{monopoles}{\longrightarrow} \mathrm{H} \overset{inflation+strings}{\longrightarrow} \mathrm{SM}$

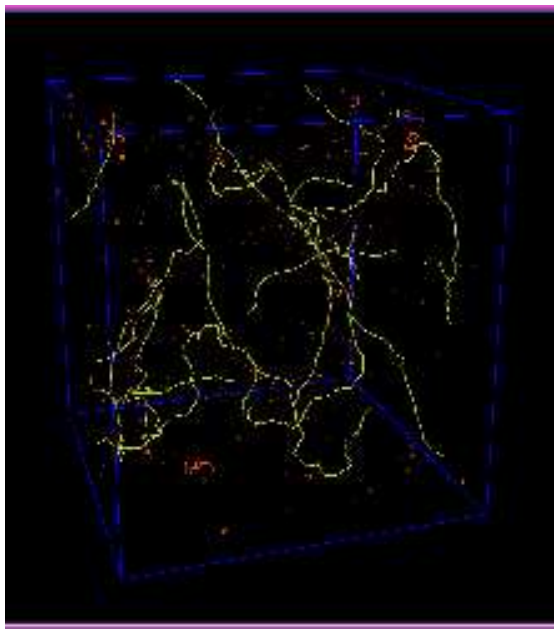
cosmic strings always form!

Jeannerot,Davis '95, Jeannerot,Rocher,Sakellariadou '03

Inflation + strings

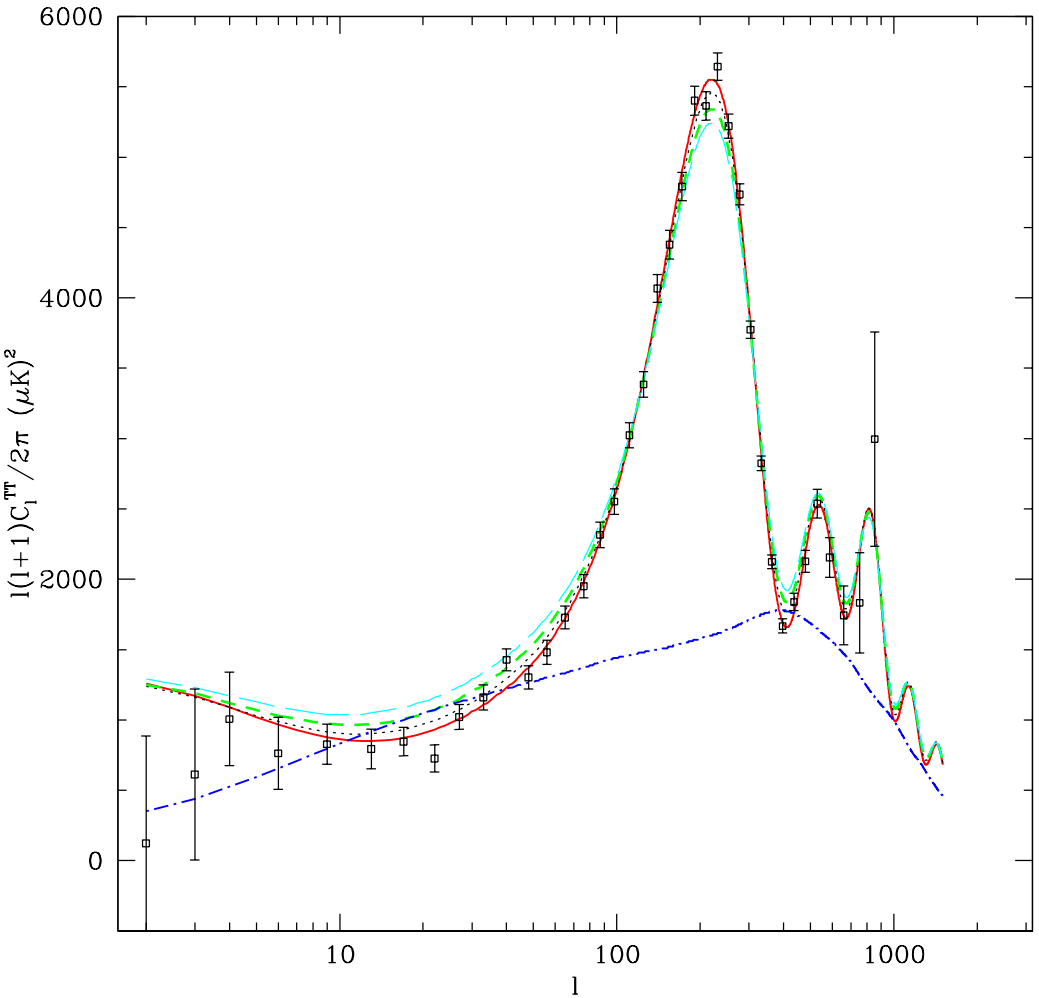


Quantum fluctuations during inflation



Allen & Shellard

Angular power spectrum of the CMB



The power spectrum predicted by inflation (red) and cosmic strings (blue).

A string contribution up to 10% (green) is allowed.

Pogosian et al '03

Density perturbations

(F-term inflation)

Perturbations from cosmic strings

$$\left(\frac{\delta T}{T}\right)_{\rm tot} = \sqrt{\left(\frac{\delta T}{T}\right)^2_{\rm infl} + \left(\frac{\delta T}{T}\right)^2_{\rm cs}} = 6.6 \times 10^{-6}$$

String contribution from simulations:

- scaling solution $L \sim t \Rightarrow \rho_{\rm cs} = \mu/L^2$
- scales: 10^{-30}cm string width - 10^3 Mpc cosmological scales
- rad/mat domination, wiggliness, ...

$$\left(\frac{\delta T}{T}\right)_{\rm cs} = yG\mu \quad \text{with } y = 9^{+3}_{-6}$$

$$\mu = 2\pi M^2 \theta(g/\kappa)$$

$$\theta = 2/\log(g^2/\kappa^2)$$

Hill, Hodges, Turner '87

$$M < 3 \times 10^{15} \sqrt{9/(y\theta)}\, GeV$$

Inflaton perturbations

$$\left(\frac{\delta T}{T}\right)_{\rm infl} = \frac{1}{12\sqrt{5}\pi}\frac{V^{3/2}}{m_{\rm p}^3 V'}$$

Tree level potential:

$$W = \kappa S(\Phi\bar{\Phi} - M^2)$$

$$V = \kappa^2 M^4$$

Rocher & Sakellariadou '04,Jeannerot & MP '05, '06

Inflaton perturbations

$$\left(\frac{\delta T}{T}\right)_{\rm infl} = \frac{1}{12\sqrt{5}\pi m_{\rm p}^3}\frac{V^{3/2}}{V'}$$

Coleman-Weinberg potential

Susy breaking $m_\pm^2 = (\kappa M)^2(x^2 \pm 1)$ & $\tilde{m}_\pm^2 = (\kappa M)^2 x^2$

$$V = \kappa^2 M^4 + \frac{\kappa^4 M^4 \mathcal{N}}{32\pi^2}\left[2\ln\left(\frac{\kappa M x}{M_*}\right) + (x^2+1)^2\ln\left(1+\frac{1}{x^2}\right) + (x^2-1)^2\ln\left(1-\frac{1}{x^2}\right)\right]$$

$\mathcal{N} = 1\text{-}3, \quad x = |S|/M$

Rocher & Sakellariadou '04,Jeannerot & MP '05, '06

Inflaton perturbations

$$\left(\frac{\delta T}{T}\right)_{\rm infl} = \frac{1}{12\sqrt{5}\pi m_{\rm p}^3}\frac{V^{3/2}}{V'}$$

Sugra corrections

- Minimal kähler: $K = |S|^2 + |\phi|^2 + |\bar{\phi}|^2$
- Hidden superpotential $W_{\rm hid}(z)$
  $\langle z\rangle = a m_{\rm p}$, $\langle W_{\rm hid}\rangle = m_{3/2} m_{\rm p}^2$, $\Lambda = 0$

$$V = \kappa^2 M^4 + \frac{\kappa^4 M^4 \mathcal{N}}{32\pi^2}\left[2\ln\left(\frac{\kappa M x}{M_*}\right) + (x^2+1)^2\ln\left(1+\frac{1}{x^2}\right) + (x^2-1)^2\ln\left(1-\frac{1}{x^2}\right)\right] + \frac{1}{2}\kappa^2 M^4\frac{|S|^4}{m_{\rm p}^4} + |a|^2 H^2 |S|^2\Big] + \kappa M^2 A m_{3/2}|S| + \cdots$$

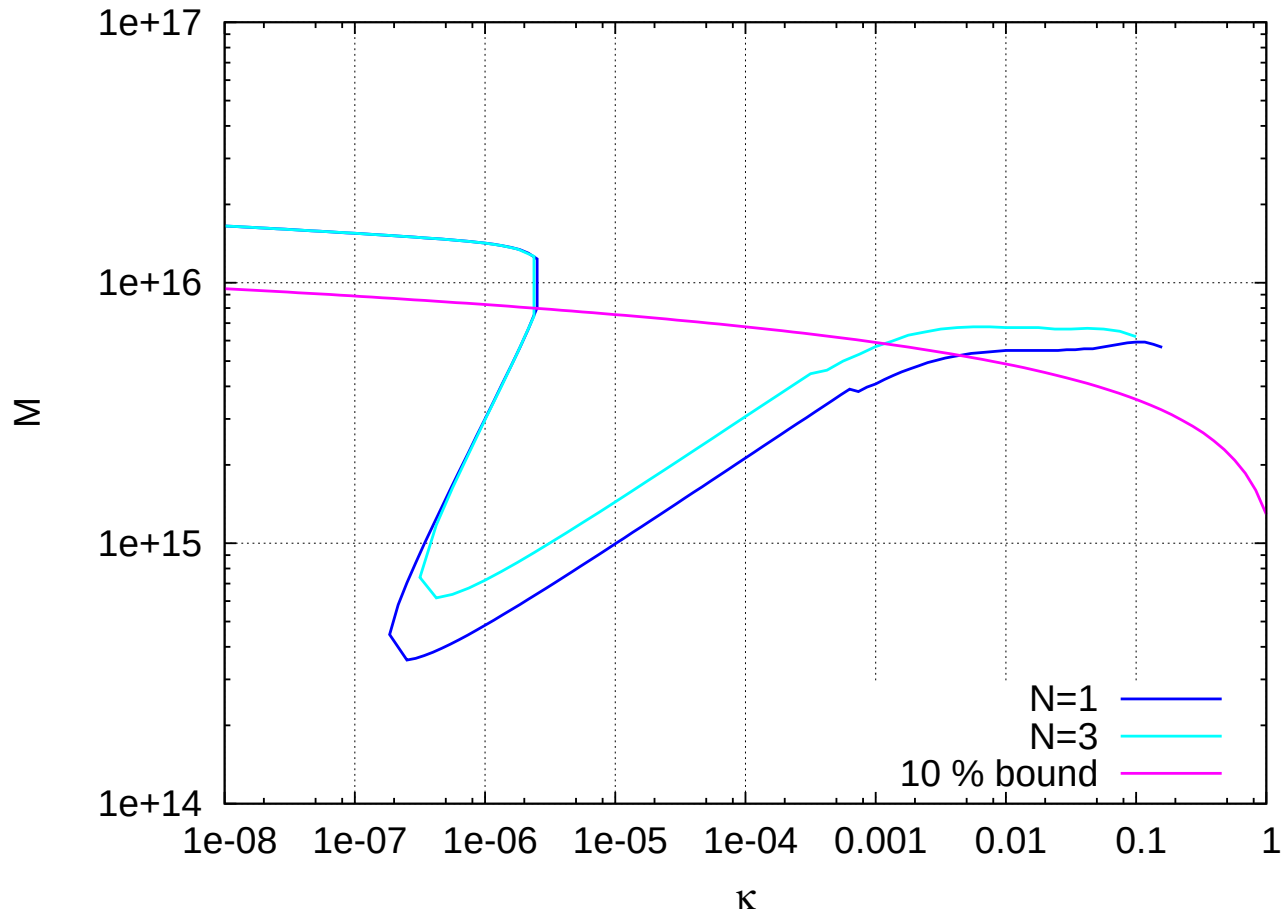
$\mathcal{N} = 1\text{-}3, \quad x = |S|/M \ , \quad A = 4\cos(\arg\mu - \arg S)$

Rocher & Sakellariadou '04, Jeannerot & MP '05, '06

CMB anisotropies — F-term

Jeannerot & MP '05

SSB scale M as function of κ.

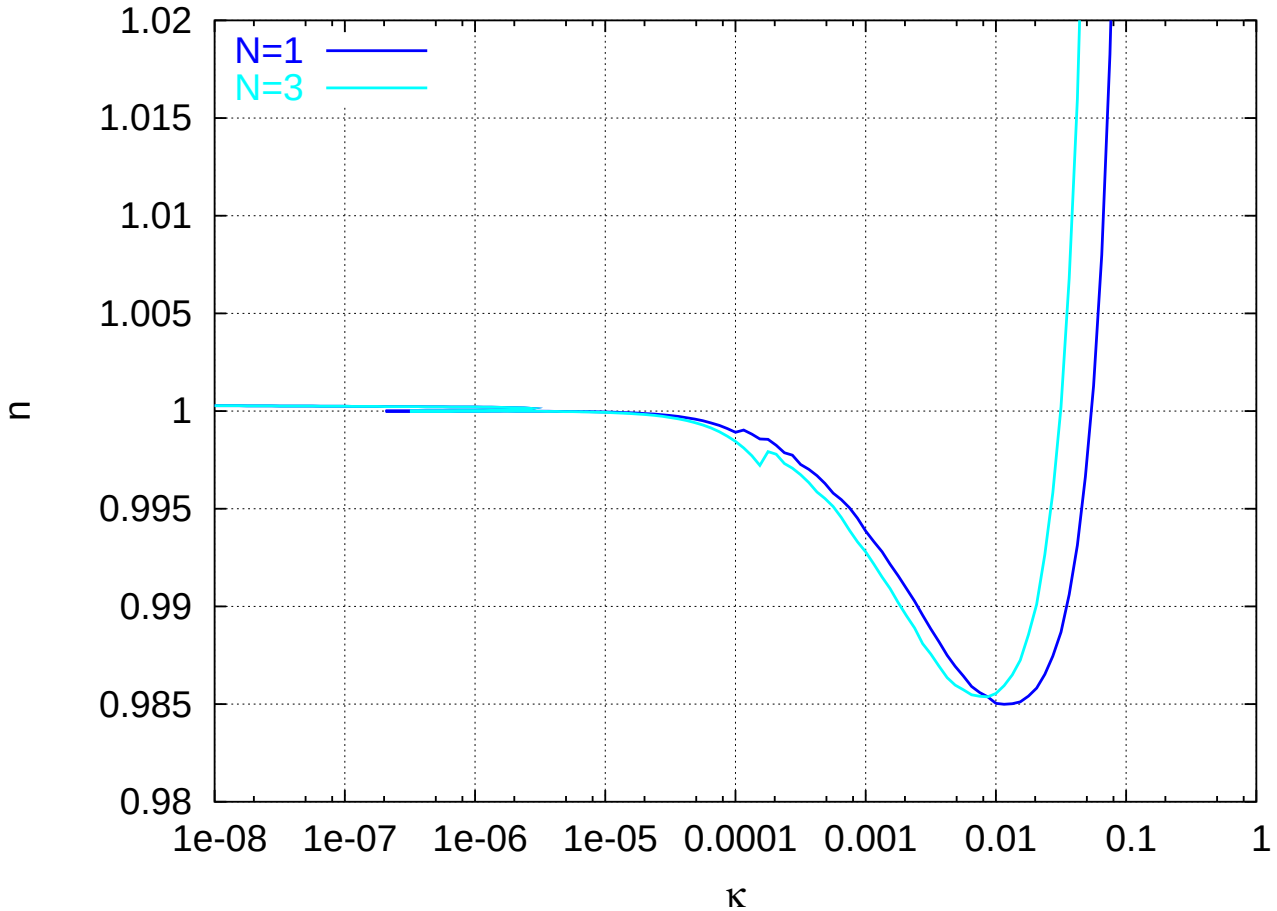


CMB anisotropies — F-term

Jeannerot & MP '05

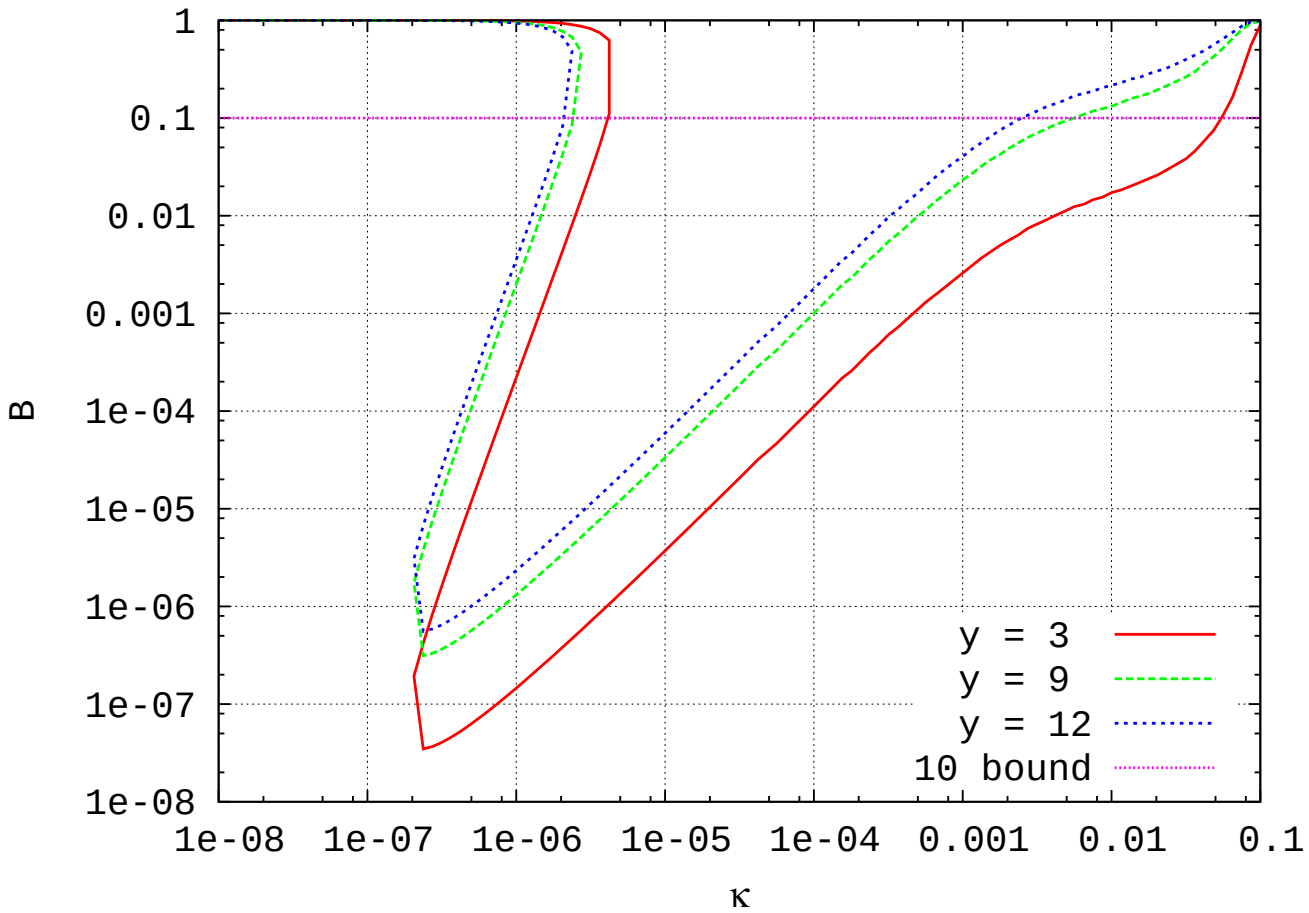
spectral index n_s as function of κ. compare w/ WMAP3 result:

$$n_s = 0.951^{+0.015}_{-0.019}$$



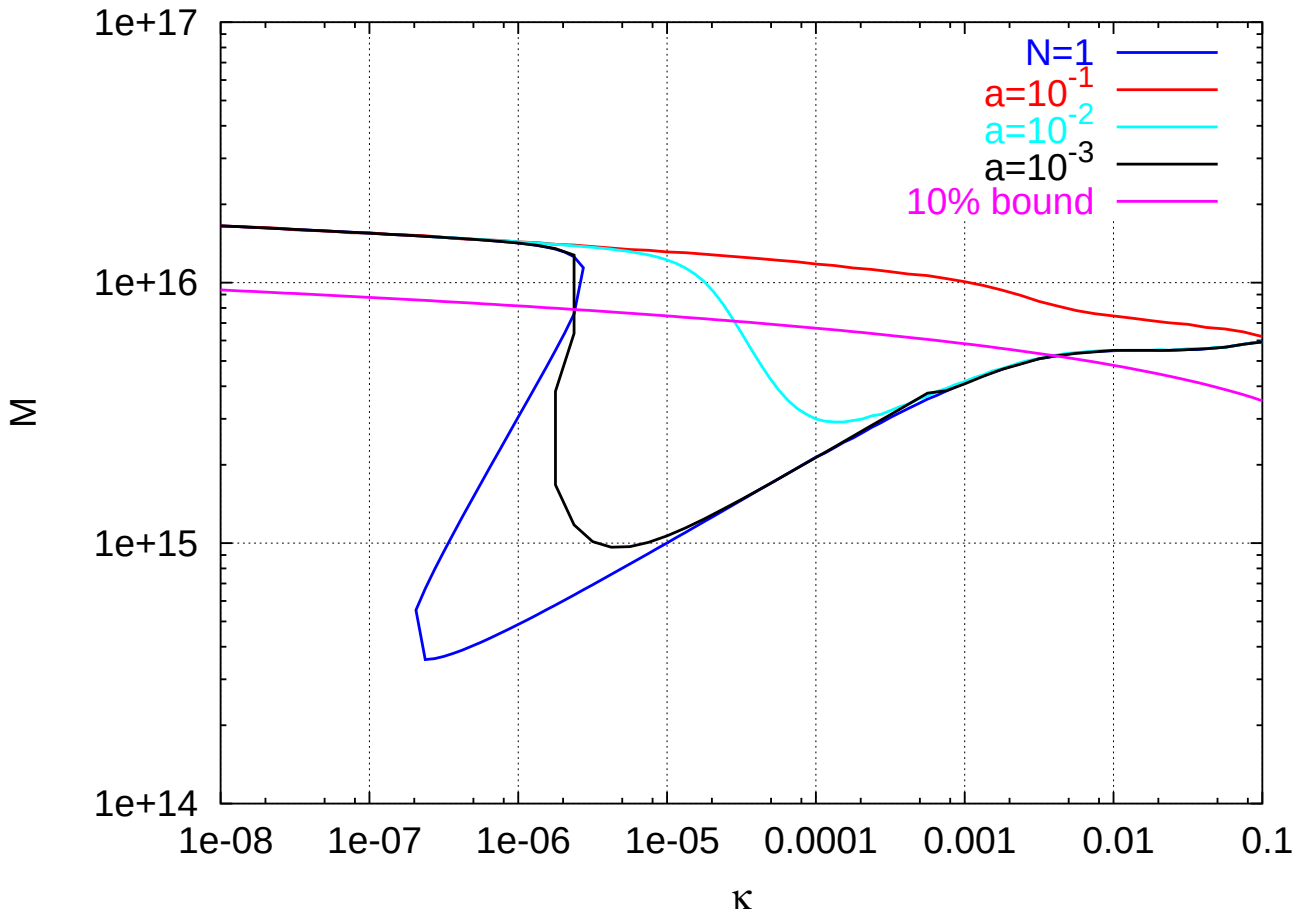
CMB anisotropies — F-term

Cosmic string contribution: $B = \left| \frac{(\delta T/T)_{\mathrm{cs}}}{(\delta T/T)_{\mathrm{COBE}}} \right|^2$



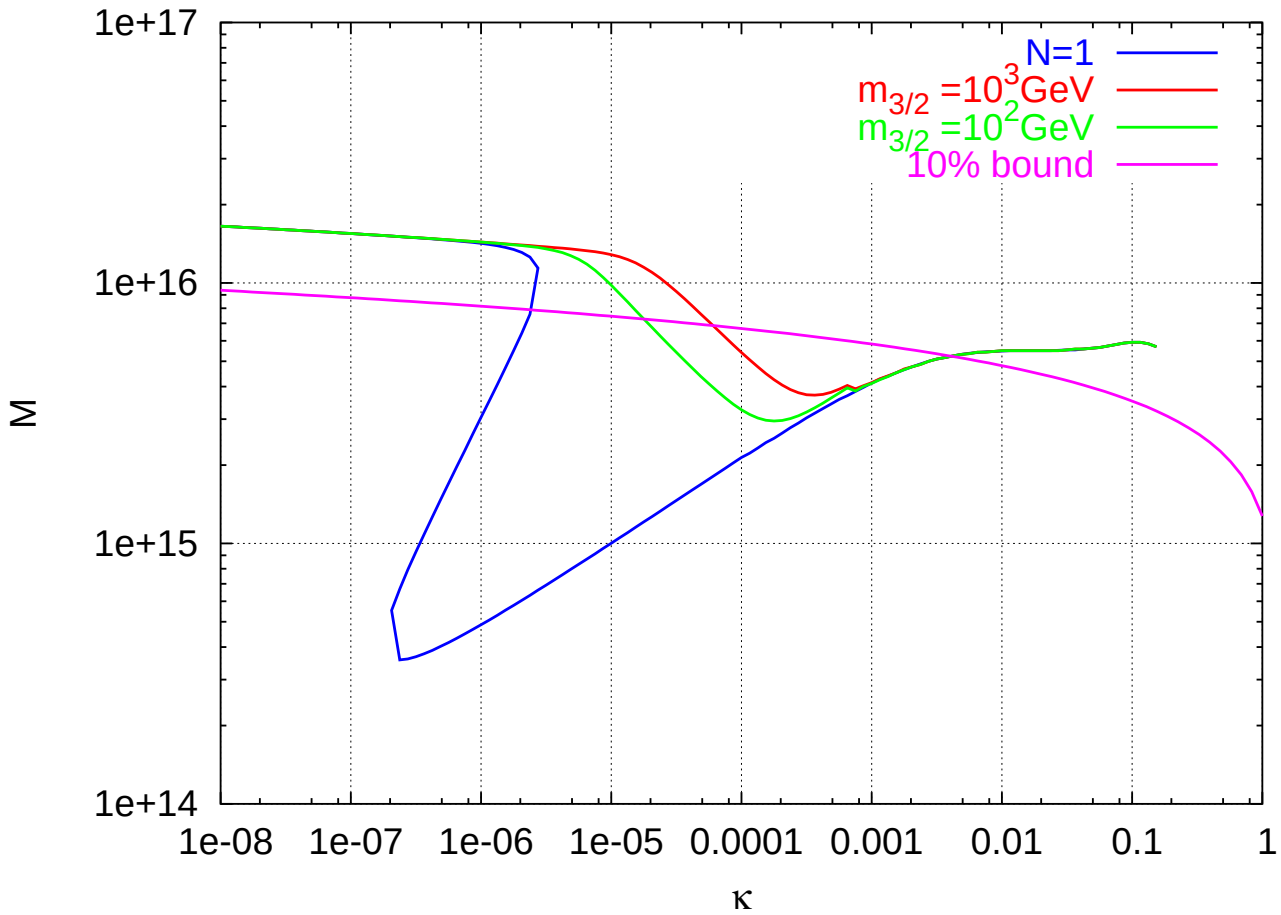
CMB anisotropies — F-term

Moduli VEV $\langle z \rangle = a m_{\rm p}$ $\Rightarrow$ $V = a^2 H^2 |S|^2$



CMB anisotropies — Fterm

Gravitino mass $m_{3/2}$ $\Rightarrow$ $V \sim \kappa M^2 m_{3/2} |S|$



Density perturbations

(D-term inflation)

Perturbations in D-term inflation

Differences:

- strings BPS $\mu = 2\pi^2\xi$
- dependence on g, κ, ξ
- less SUGRA corrections ($W = 0$)
- large inflaton $S > S_c \approx \frac{g\sqrt{\xi}}{\kappa}$ (for $S < m_{\rm p}$)

$$V = \frac{1}{2}g^2\xi^2 + \frac{g^2\xi^2}{32\pi^2}\left[2\ln\left(\frac{\kappa\xi x}{M_*}\right) + (x^2+1)^2\ln\left(1+\frac{1}{x^2}\right) + (x^2-1)^2\ln\left(1-\frac{1}{x^2}\right)\right]$$

with

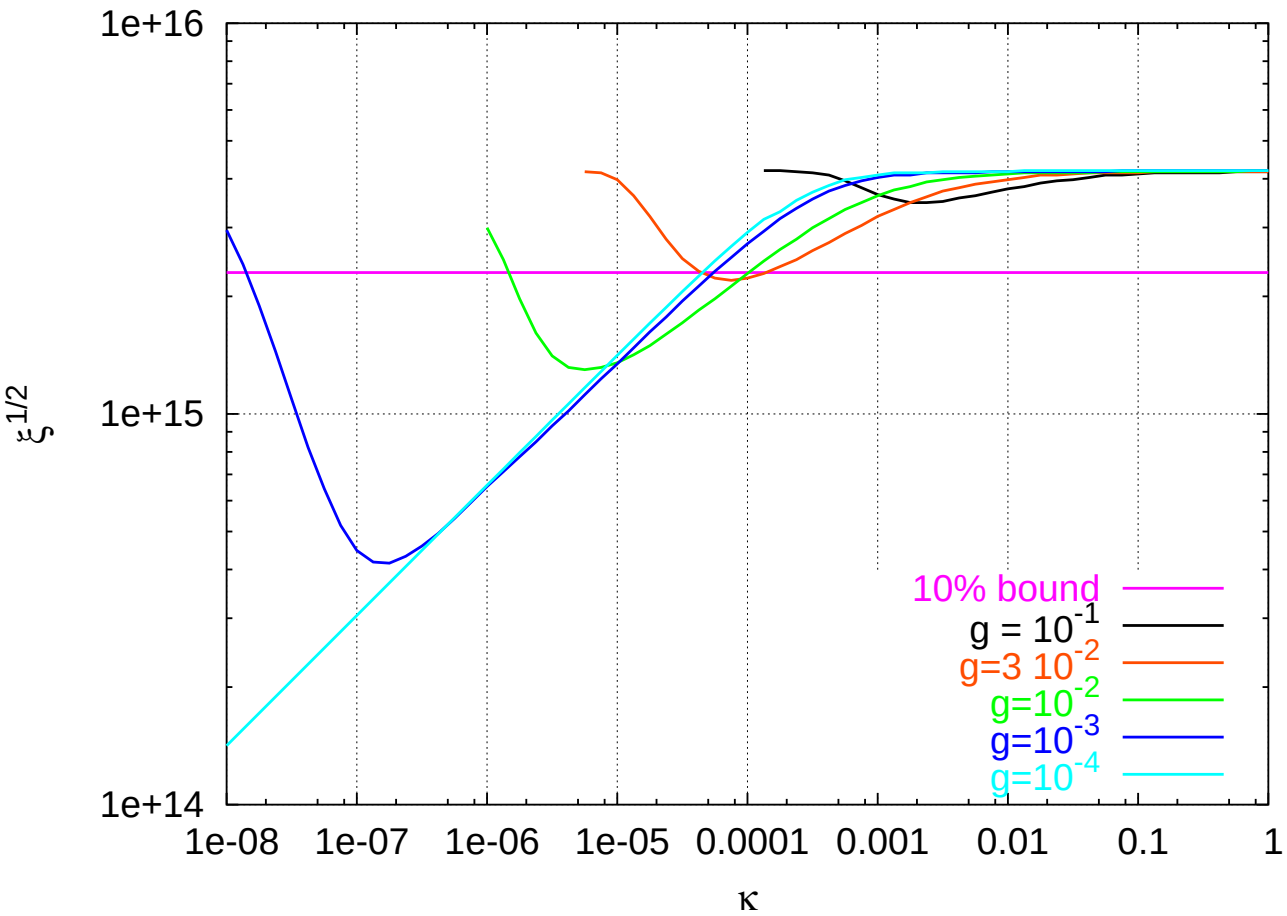
$$x = \mathrm{e}^{|S|^2/(2m_{\rm p}^2)}\,\frac{\kappa|S|}{g\sqrt{\xi}}$$

Rocher & Sakellariadou '04, Jeannerot & MP '05, '06

CMB anisotropies — D-term

Jeannerot & MP '05

FI-term $\sqrt{\xi}$ as function of κ. Need $g < 01^{-2}$!



CMB anisotropies — D-term

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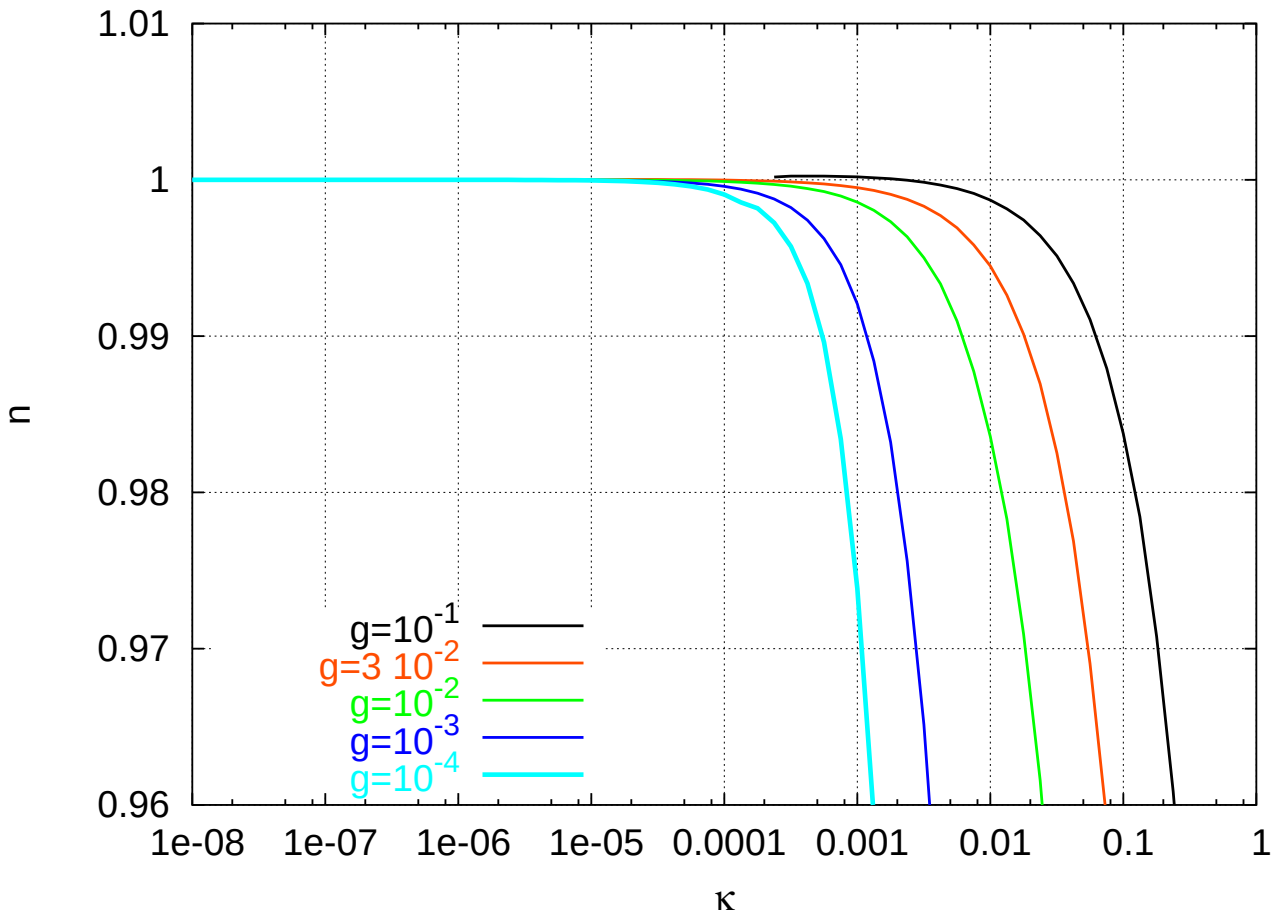
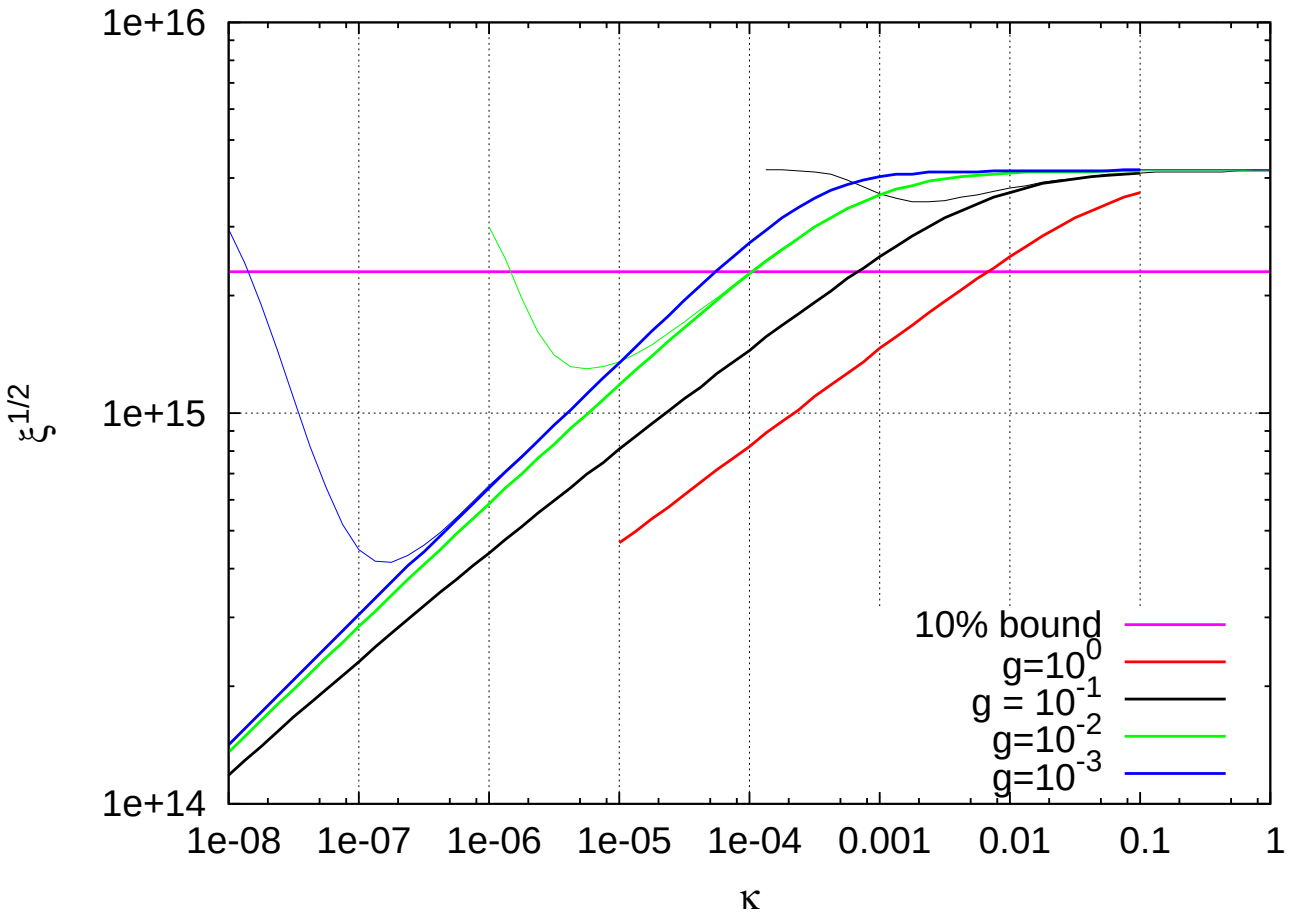


CMB anisotropies — D-term

Shift symmetry in Kahler $K = \frac{1}{2}|S - \bar{S}|^2 + |\phi|^2 + |\bar{\phi}|^2$.

Then $x = \frac{\kappa|S|}{g\sqrt{\xi}}$ (no factor $\mathrm{e}^{|S|^2/(2m_{\mathrm{p}}^2)}$).



Conclusions

Cosmic strings always form at the end of standard SUSY hybrid inflation

F-term:
inflaton-Higgs coupling $10^{-7} < \kappa < 10^{-3}$ with $n_s \approx 1$
moduli field $\langle z \rangle < 0.1 m_{\rm p}$
gravitino mass $m_{3/2} < 1\text{TeV}$

D-term:
inflaton-Higgs coupling $\kappa < 10^{-4}$ & $g < 10^{-2}$ with $n_s \approx 1$
shift symmetry: $\lambda < 10^{-2}$ with n_s

NB1: bounds order of magnitude stronger with pulsar bound on strings

Conclusions

NB2: string bound avoided:

- semi-local strings (add extra Higgs pair) Achucarro et al
- non standard potential (hard!) eg. shifted or smooth inflation
- curvaton/inhomogeneous reheat scenario (ugly!)
- GUTs: R-parity put in by hand -> strings non-topological