Racetrack Inflation as Pseudo-Goldstone Inflation

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HEP Znaleziono **15** rekordów Szukanie trwało 0.16 sekund.

1. **Hybrid Natural Low Scale Inflation.**
Graham G. Ross (Oxford U., Theor. Phys. & CERN), Gabriel German (UNAM, CCF). Feb 2010.
Published in **Phys.Lett. B691 (2010) 117-120**
e-Print: **arXiv:1002.0029 [hep-ph]**

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2. **Hybrid natural inflation from non Abelian discrete symmetry.**
Graham G. Ross (Oxford U.), Gabriel German (Mexico U., Cuernavaca). OUTP-09-05P. Feb 2009. 9 pp.
Published in **Phys.Lett. B684 (2010) 199-204**
e-Print: **arXiv:0902.4676 [hep-ph]**

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3. **Fine tuning and the ratio of tensor to scalar density fluctuations from cosmological inflation.**
Shaun Hotchkiss, Gabriel German, Graham G. Ross (Oxford U., Theor. Phys.). OUTP-08-05P. Apr 2008. 9 pp.
Published in **JCAP 0810 (2008) 015**
e-Print: **arXiv:0804.2634 [astro-ph]**

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4. **Non-isotropy in the CMB power spectrum in single field inflation.**
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7. **Implementing quadratic supergravity inflation.**
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9. **Multiple inflation.**
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10. **Multiple inflation.**
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11. **Large scale structure from supersymmetric inflation.**
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12. **Natural supergravity inflation.**
Jennifer A. Adams (Uppsala U.), Graham G. Ross, Subir Sarkar (Oxford U.). OUTP-96-48-P. Aug 1996. 14 pp.
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14. **Inflation As A Cure For The Cosmological Problems Of Superstring Models With Intermediate Scale Breaking.**
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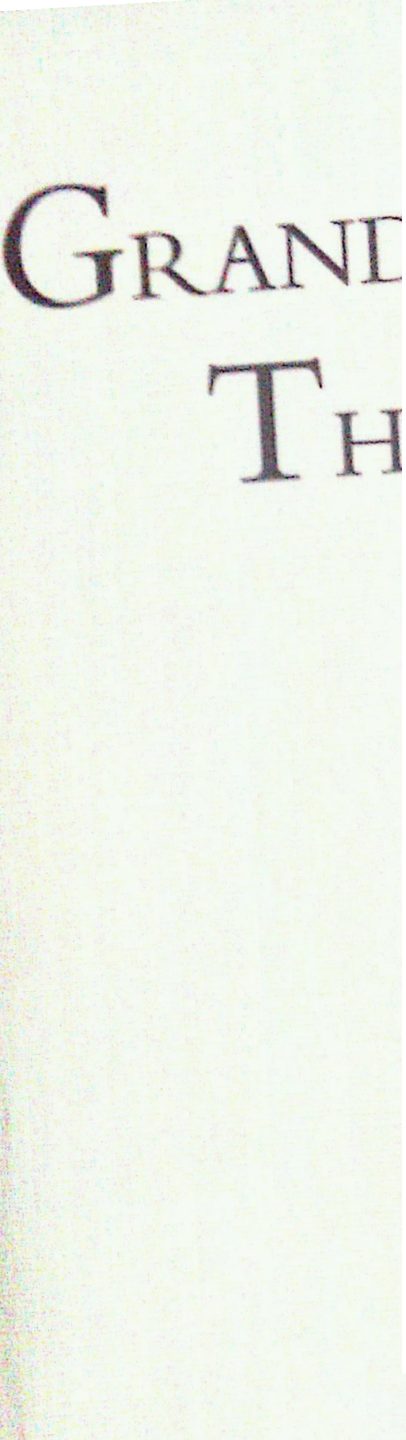

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Nuclear Physics B 766 (2007) 1–20

Racetrack inflation and assisted moduli stabilisation

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Abstract

We present a model of inflation based on a racetrack model *without* flux stabilization. The initial conditions are set automatically through topological inflation. This ensures that the dilaton is not swept to weak coupling through either thermal effects or fast roll. Including the effect of non-dilaton fields we find that moduli provide natural candidates for the inflaton. The resulting potential generates slow-roll inflation without the need to fine-tune parameters. The energy scale of inflation must be near the GUT scale and the scalar density perturbation generated has a spectrum consistent with WMAP data.

$$\epsilon \equiv \frac{m_P^2}{2}\left(\frac{V'}{V}\right)^2, \; \eta \equiv m_P^2\left(\frac{V''}{V}\right) \ll 1$$

$$n_s = 1 - 6\epsilon + 2\eta$$

$$r = 16\epsilon \qquad dn_s/d\ln k$$

} ***Observables***

chaotic

$$V(\phi) = \frac{1}{2}m^2\phi^2\left(1 + \frac{1}{2}\kappa_c^2\phi^2\right)$$

new, or symmetry-breaking

$$V(\phi) = \lambda M_P^4\left(1 - \kappa_s^2\frac{\phi^2}{M_P^2}\right)^2$$

} ***Simple potentials consistent with WMAP3***

Can any of these potentials be embedded in supergravity?

In 4d N=1 SUGRA

$$L_{kin} = K_{ij} D_\mu \Phi^i D^\mu \bar{\Phi}^j$$

$$V = e^K [K^{ij}(W_i + K_i W)(\bar{W}_j + \bar{K}_j \bar{W}) - 3|W|^2]$$

For canonically normalised fields $K = \Phi\bar{\Phi}$

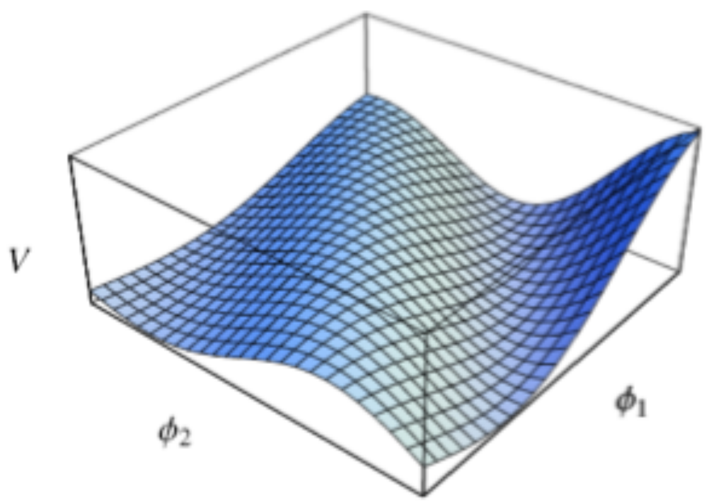
and

$$V = e^{|\Phi|^2}\{...\} \rightarrow \eta \sim O(1)$$

So typically slow-roll rather difficult to achieve

couplings ⟷ **expectation values of gauge-singlet fields**

e.g. $Re(S)F^2$



- Some of these fields have flat (or trivial) potentials at classical/perturbative level
- These flat directions are called **moduli**
- Examples: dilaton *S*: $<\mathrm{Re}(S)>= e^{\varphi}$

  volume modulus *T*: $<\mathrm{Re}(T)-|\Phi|^2>= R^2$

Theoretical requirement: stabilise $m_{EW} < m_{t,s} \ll M_P$

Dimensional transmutation - condensation

At string scale M:

$$\frac{4\pi}{g_i^2(M)} = \frac{4\pi}{g_s^2} + \frac{\Delta_i}{4\pi}$$

$$\mathrm{Re}(S) = 2\pi/\alpha_s$$

RGE running

$$\frac{1}{\alpha(Q)} = \frac{1}{\alpha(\mu)} + \frac{b_0'}{2\pi}\log\left(\frac{Q}{\mu}\right)$$

$$SU(N) \text{ with } K \times (N + \bar{N}) \rightarrow b_0' = 3N - K$$

$$1/\alpha(Q) \rightarrow 0$$

Condensation scale

$$\Lambda = M e^{-\mathrm{Re}(S)/b_0'}$$

$$\Lambda = M \mathrm{e}^{-\mathrm{Re}(S)/b_0} \left|\frac{M}{m}\right|^{(b_0'-b_0)/b_0}$$

$$\delta W = (\alpha + \beta\chi)\Psi\Psi \quad \Longrightarrow \quad m = \alpha + \beta\langle\chi\rangle$$

$$L_k = \frac{\mathrm{Re}(f(S))}{4} F^2 \rightarrow W_{\mathrm{npert}} = A N_1 M^3 \mathrm{e}^{-S/N_1}$$

$$f(S) = \tfrac{S}{8\pi^2}$$

$$f(S,\chi) = \frac{S}{8\pi^2} - \frac{b_0'-b_0}{8\pi^2} \log\left(\frac{M}{\alpha+\beta\chi}\right)$$

$$\Big\Downarrow$$

$$W = C M^3 \mathrm{e}^{-24\pi^2 f(S,\chi)/b_0}$$

Racetrack

$$W_{\rm npert} = AN_1M^3{\rm e}^{-S/N_1} - BN_2M^3{\rm e}^{-S/N_2}\left(\frac{M^2}{(\alpha+\beta\chi)^2}\right)^{3(N_2'-N_2)/(2N_2)}$$

$$K = -3\log(T+\bar{T}) - \log(S+\bar{S}) + \chi\bar{\chi}$$

$$S = s + i\phi,\ \chi = x\,{\rm e}^{i\theta},\ T = t + i\eta$$

To stabilise T:

$$V_D = \frac{g^2}{2}(f_1(t)|\Phi_1|^2 - \xi)^2$$

Scalar potential:

$$V(S) = \frac{1}{2s}\kappa\left|A(2s+N_1){\rm e}^{-s/N_1} - B{\rm e}^{-i\epsilon\phi}(\alpha+\beta\chi)^{-2\gamma}(2s+N_2){\rm e}^{-s/N_2}\right|^2 e^{|\chi|^2}$$
$$+\frac{|\chi|^2}{2s}\kappa\left|AN_1{\rm e}^{-s/N_1} - B{\rm e}^{-i\epsilon\phi}(\alpha+\beta\chi)^{-2\gamma}N_2{\rm e}^{-s/N_2}\left(1-\frac{2\gamma\beta}{\alpha\bar{\chi}+\beta|\chi|^2}\right)\right|^2 e^{|\chi|^2}$$

$$\epsilon = (N_1 - N_2)/(N_1N_2) \qquad \gamma = 3(N_2' - N_2)/(2N_2)$$

$$\kappa = 1/(8t^3)$$

Pure dilaton racetrack

$$V(s,\phi) = \frac{1}{2s}\left(A(2s+N_1)e^{-s/N_1} - B(2s+N_2)e^{-s/N_2}\right)^2$$
$$+\frac{1}{s}AB(2s+N_1)(2s+N_2)e^{-(s/N_1+s/N_2)}\,(1-\cos(\phi\epsilon))$$

$$s_{\min} = \frac{1}{\epsilon}\log\left(\frac{B}{A}\right), \qquad s_{\max} = \frac{1}{\epsilon}\log\left(\frac{BN_1}{AN_2}\right)$$

$$\eta = 2s_{\max}^2\frac{\log(\frac{BN_1}{AN_2})}{N_1-N_2}$$

LARGE!
in WCL

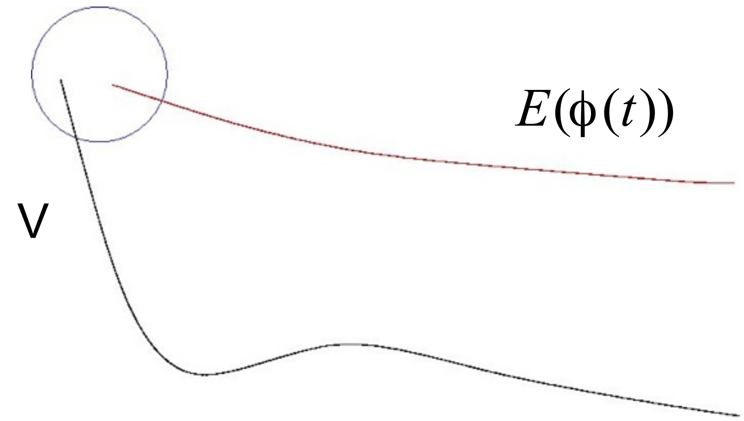
$$\eta_\phi = (\epsilon s)^2\frac{\cos(\epsilon\phi)}{1-\cos(\epsilon\phi)}$$

could be small

but $\cos^2(\epsilon\phi) > 4(N_2/N_1)/(1+N_2/N_1)^2$

Rapid Roll

Brustein and Stainhardt



$$V(s) = V(e^{\phi}) = e^{-e^{\phi}/N}$$

$$a(t) = t^{1/3}$$

$$\phi_{tt} + \frac{1}{t}\phi_t - \frac{k^2}{t^{2/3}}\phi = 0$$

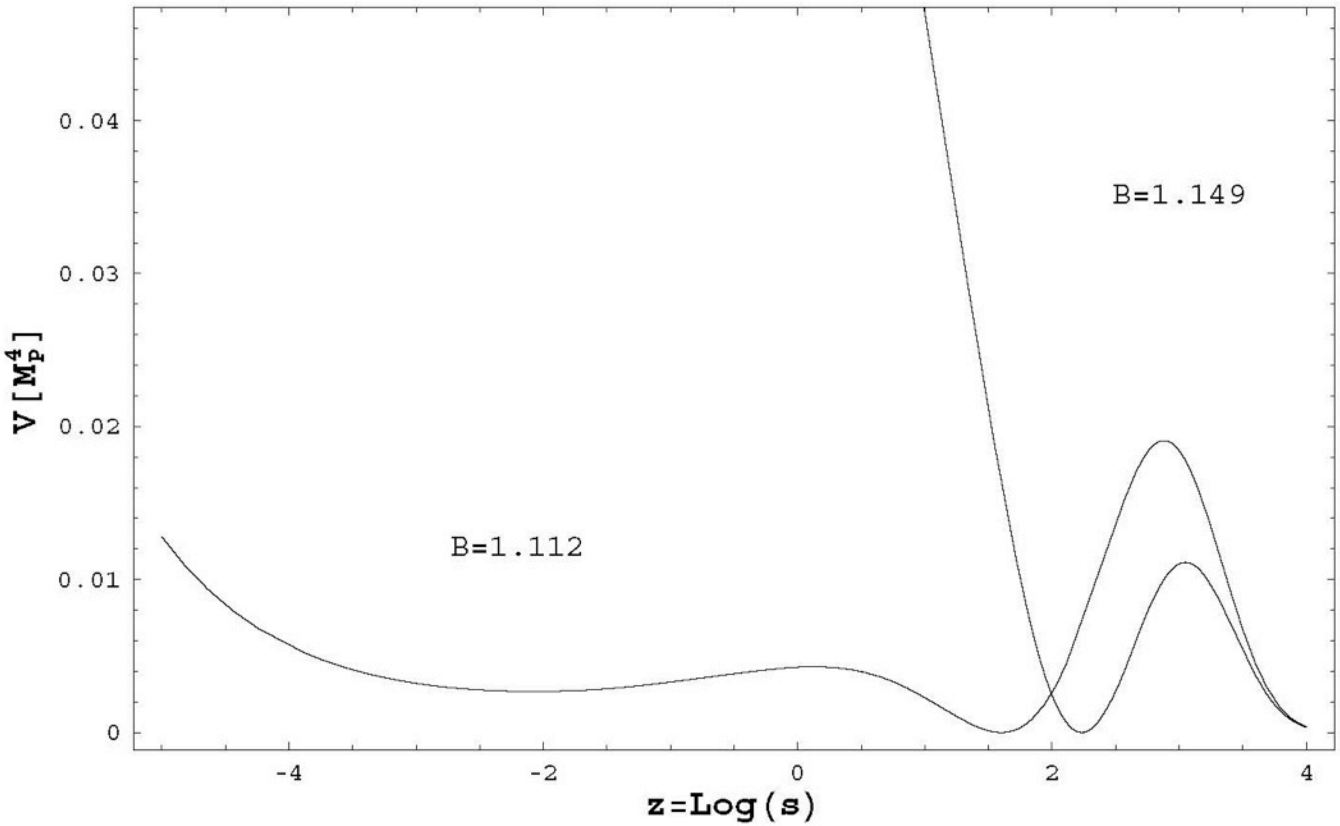
$$k = 0: \quad \phi(t) \sim \log(t)$$

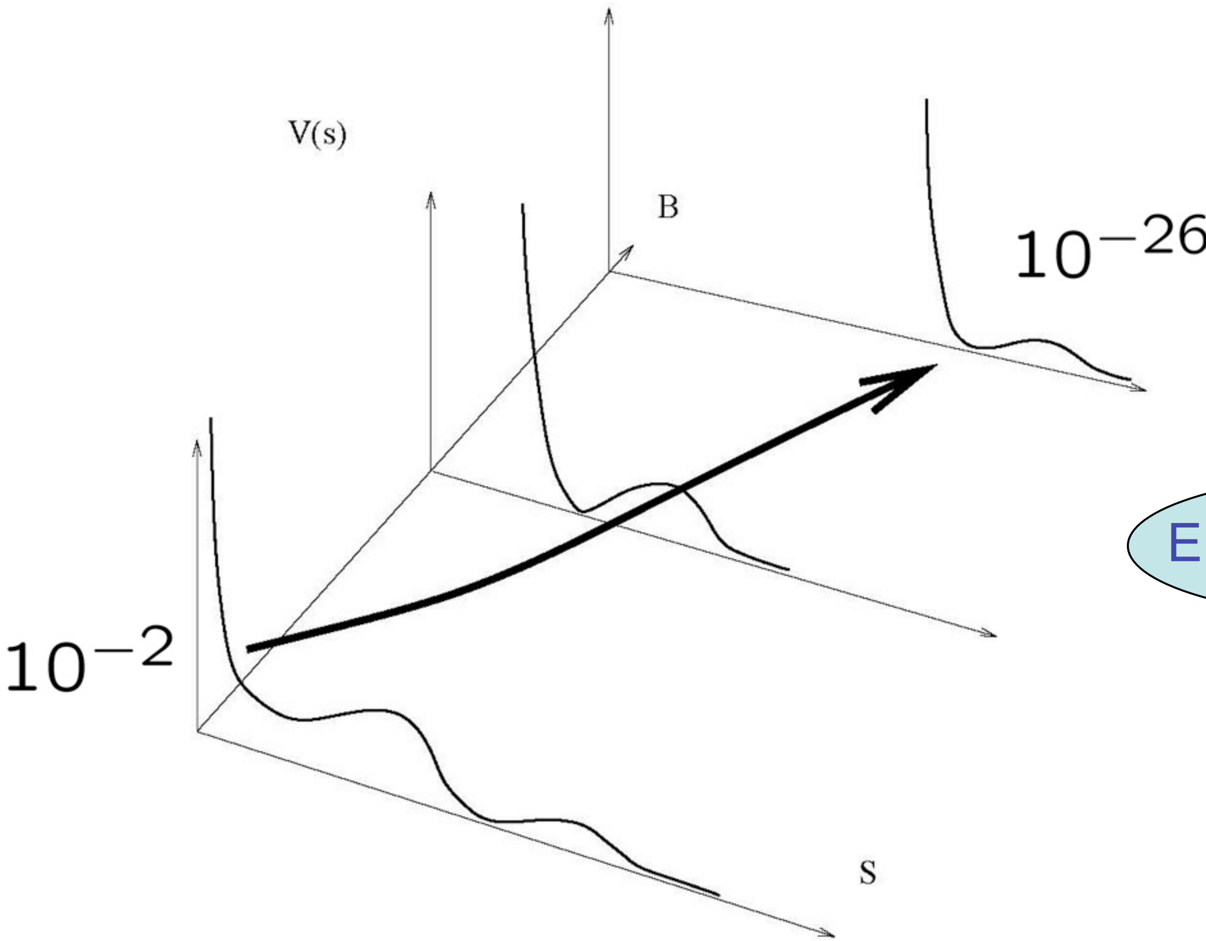
$$EK_0 \sim \frac{1}{t^2} \sim \frac{1}{a^6} \quad vs \quad V(\phi) \sim e^{-t/N} \sim e^{-a^3/N}$$

$$k \neq 0: \quad \phi_k(t) \sim \frac{1}{t^{1/3}} \cos(\tfrac{3}{2}k\, t^{2/3})$$

$$EK_K \sim \frac{1}{a^4} \rightarrow a(t) = t^{1/2} \rightarrow \phi(t) = \alpha t^{-1/2} + \beta$$

Entropy production





Entropy production

$$V_{\text{weak barrier}} = m_{3/2}^2 \left[\frac{8\pi}{g^2} + \frac{1}{\epsilon} \log \left(\frac{N_1}{N_2} \right) \right] \frac{8\pi}{g^2}$$

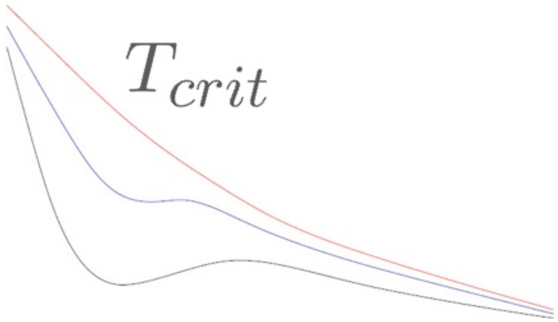
$$\frac{V_i ni}{V_f in} = 10^{24}$$

Thermal effects and the thermal roll problem

Buchmueller et al.

$$V_{\rm tot} = V(s) + F(g,T) = V(s) - \frac{\pi^2 T^4}{24}\left(a_0 + a_2 g^2 + \mathcal{O}(g^3)\right)$$

$$a_0 > 0,\ a_2 < 0$$



Ellis et al., Enqvist et al.

$$\Gamma_{\rm int} = \alpha_s^2 T$$

$$H_{\rm hot} = \sqrt{N_{\rm eff}}\, T^2 / M_{\rm P}$$

$$\Gamma_{\rm int} > H_{\rm hot}$$

$$T < T_{\rm eq} = M_{\rm P} \frac{\alpha_s^2}{\sqrt{N_{\rm eff}}} \Rightarrow T_{eq} = 3 \times 10^{14}\,\mathrm{GeV}$$

$$V_{inflation}^{1/4} > \sqrt{\alpha_s^2 T_{eq} M_P} \sim 3 \times 10^{15}\,\mathrm{GeV}$$

$$T_{\rm rh} < 10^8 - 10^{10}\,\mathrm{GeV} < T_{eq}$$

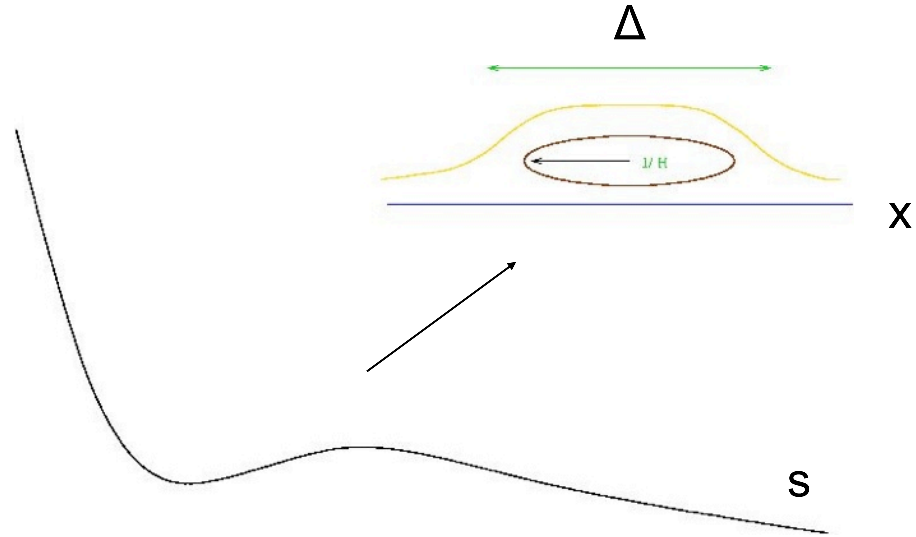
from gravitino production

Topological inflation

$$\left(\frac{2\delta}{\Delta}\right)^2 = V(s_{\mathrm{max}})$$

$$z = \log(s)$$

$$\delta = \log(s_{\mathrm{max}}/s_{\mathrm{min}})$$



$$\Delta/H^{-1} = \sqrt{32\pi/3}\,\log\left(1 + N_1 N_2 \log(N_1/N_2)/s_{\mathrm{min}}\right)$$

$$V(z_{1/n}) = V_0/n$$

$$\frac{\Delta^2}{H^{-2}} = \frac{32\pi}{3}\frac{2(n-1)}{n}\frac{1}{\eta}$$

Details of the model

$$W_{\text{npert}} = \chi^p A N_1 M^3 \mathrm{e}^{-S/N_1} - \chi^{p'} B N_2 M^3 \mathrm{e}^{-S/N_2} \left(\frac{M^2}{(\alpha+\beta\chi)^2}\right)^{3(N_2'-N_2)/(2N_2)}$$

with $p = p'$

$$\begin{aligned} V(s,\phi,x,\theta) \;=\; & \frac{e^{x^2}}{2s}\kappa x^{2p}\Big(A^2(2s+N_1)^2\mathrm{e}^{-2s/N_1} + B^2(2s+N_2)^2\mathrm{e}^{-2s/N_2} r^{-4\gamma}(x,\theta) \\ & -2AB(2s+N_1)(2s+N_2)\mathrm{e}^{-s(\frac{1}{N_1}+\frac{1}{N_2})} r^{-2\gamma}(x,\theta)\cos[\epsilon\phi + 2\gamma\delta(x,\theta)]\Big) \\ & +\frac{e^{x^2}}{2s}\kappa x^{2p}(1+\frac{p}{x^2})^2\Big(x^2A^2N_1^2\mathrm{e}^{-2s/N_1} + B^2N_2^2\mathrm{e}^{-2s/N_2} r^{-4\gamma}(x,\theta) r'^2(x,\theta) \\ & -2xABN_1N_2\mathrm{e}^{-s(\frac{1}{N_1}+\frac{1}{N_2})} r^{-2\gamma}(x,\theta) r'(x,\theta)\cos(\epsilon\phi + 2\gamma\delta(x,\theta) - \delta'(x,\theta))\Big) \end{aligned}$$

where

$$r^2(x,\theta) = [\alpha + \beta x\cos(\theta)]^2 + \beta^2 x^2 \sin^2(\theta),$$

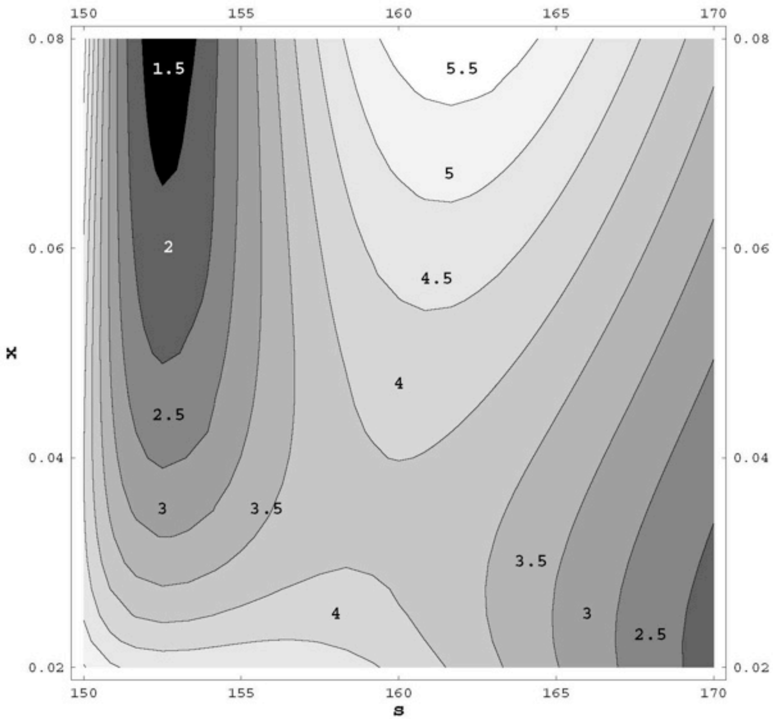
$$r'^2(x,\theta) = \left(x - 2\tilde{\gamma}(x)\beta\frac{\beta x+\alpha\cos(\theta)}{\beta^2x^2+\alpha^2+2\alpha\beta x\cos(\theta)}\right)^2 + \frac{4\tilde{\gamma}^2(x)\beta^2\alpha^2\sin^2(\theta)}{(\beta^2x^2+\alpha^2+2\alpha\beta x\cos(\theta))^2},$$

$$\tan[\delta(x,\theta)] = \frac{\beta x\sin(\theta)}{\alpha+\beta x\cos(\theta)},$$

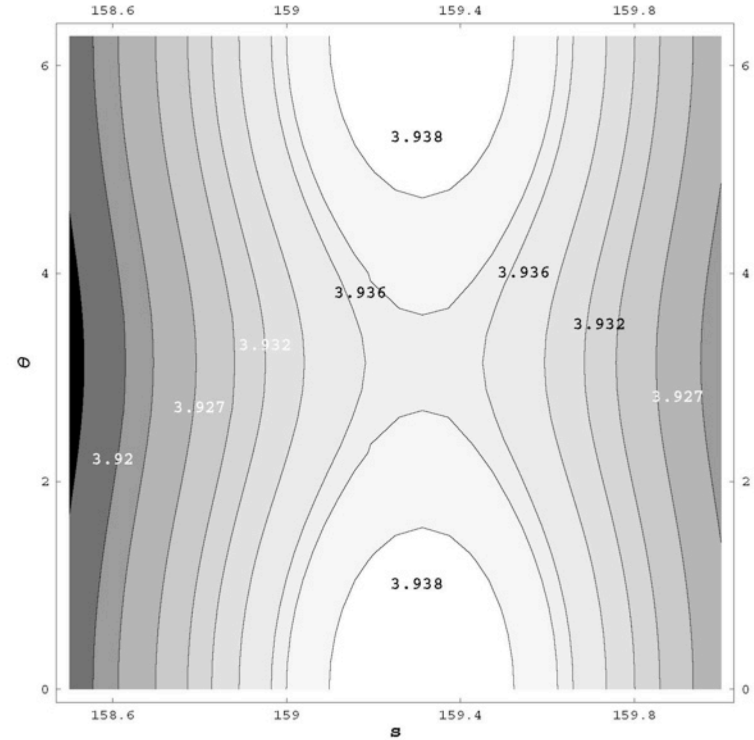
$$\tan[\delta'(x,\theta)] = \frac{2\tilde{\gamma}(x)\beta\alpha\sin(\theta)}{\beta^2x^2+\alpha^2+2\alpha\beta x\cos(\theta)}\left(x - 2\tilde{\gamma}(x)\beta\frac{\beta x+\alpha\cos(\theta)}{\beta^2x^2+\alpha^2+2\alpha\beta x\cos(\theta)}\right)^{-1},$$

$$\tilde{\gamma}(x) = \gamma(1+\frac{p}{x^2})^{-1}$$

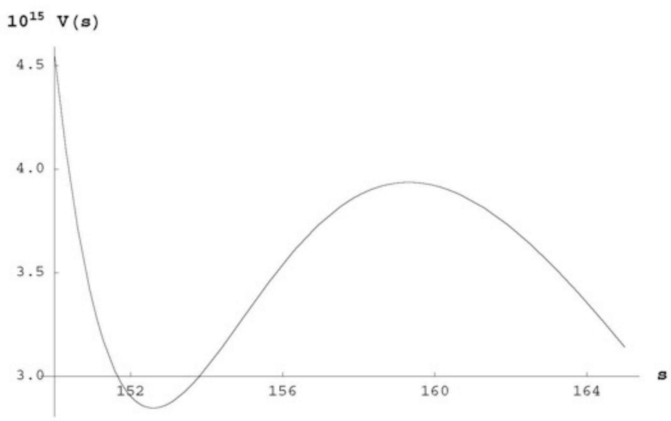
Solution



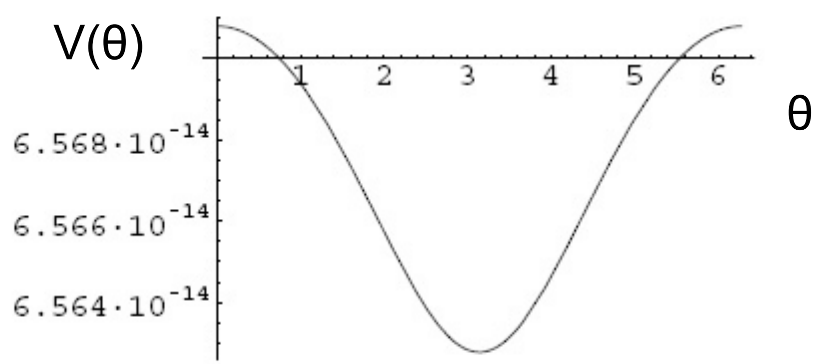
150
155
160
165
170
0.08
0.06
0.04
0.02
x
s
1.5
2
2.5
3
3.5
4
4.5
5
5.5



158.6
159
159.4
159.8
0
2
4
6
θ
s
3.938
3.936
3.932
3.927
3.92

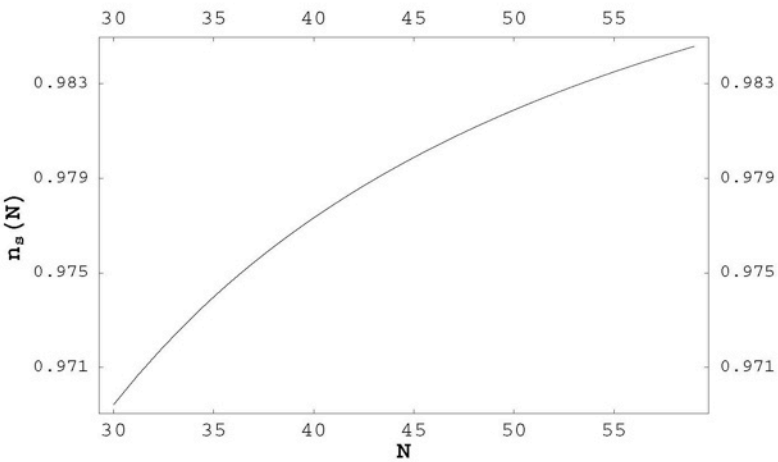


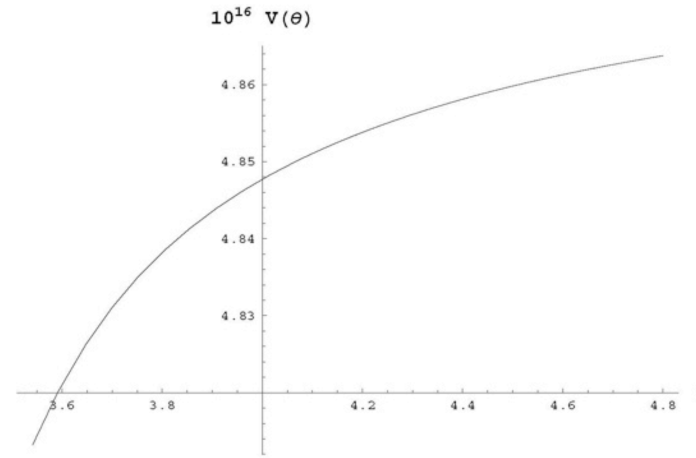
10^{15} V(s)
4.5
4.0
3.5
3.0
152
156
160
164
s



V(θ)
θ
1
2
3
4
5
6
$6.568 \cdot 10^{-14}$
$6.566 \cdot 10^{-14}$
$6.564 \cdot 10^{-14}$

$$A = 1.5,\ B = 8.2,\ N_1 = 10,\ N_2 = 9,$$
$$p = 0.5,\ \alpha = 1,\ \beta = 2.3,\ \gamma = 10^{-4}$$





Minimum:

$s = 152.6,\ \phi = 0,\ x = 0.42,\ \theta = 3.16$

Inflation:

$\theta_\star = 4.71,\ \theta_e = 3.54,\ \eta_\star = -0.0089,\ n_\star = 0.98$

$N_e \approx 8000$

Trouble:

$$V_{infl}^{1/4} > T_{eq} \to m_{3/2} > 1\,TeV$$

- Reducing $m_{3/2}$ reduces the ridge between the finite and the noninteracting vacua

  Topological trapping may still work, but probability of populating finite vacuum reduced

- **Reduce the scale of V adiabatically after inflation**

- $$W = XW_R \to V = |W_R|^2 + |X|^2|W_R'|^2$$

  Produce gravitino mass somewhere else

- **SUSY breaking with gauge mediation? Models with dynamical scales?**

Thanks Graham!

We still have papers to write!