Models of Inflation in Supergravity

Talk by **Stefan Antusch**

based on collaborations with:
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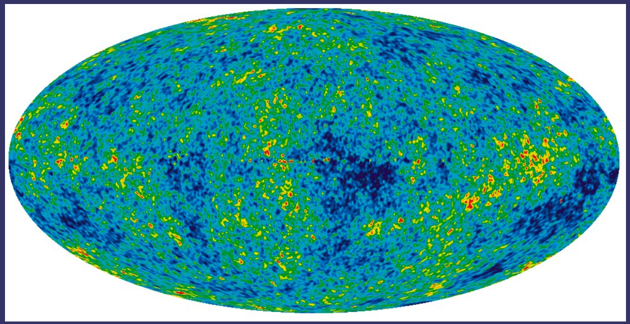
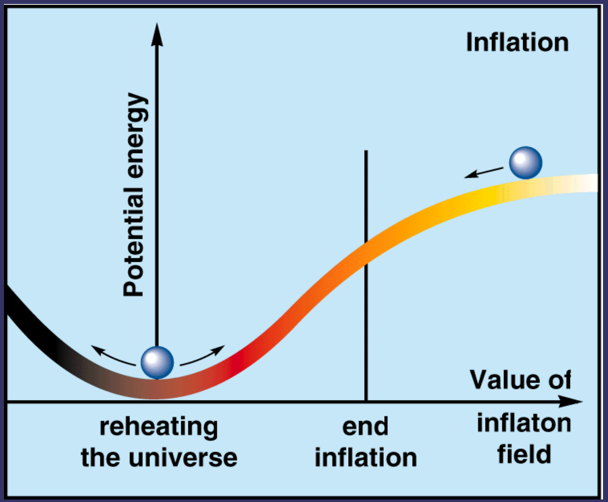
Overview

- Introduction and Motivation
- The η-problem in supergravity and strategies for its solution
- Classes of particle physics models of SUGRA inflation
- Possibilities for solving the η-problem in these classes of models
- Concluding remarks

The paradigm of cosmic Inflation



- The observed universe appears
  - almost flat
  - homogenous and isotropic on large scales (with inhomogenities on smaller scales)
  - free of relic species (monopoles, ...)



- Inflation provides a sucessful paradigm for solving these **flatness**, **horizon** and **cosmic relic problems!**

A. Guth ('81), A. D. Linde ('82), A. Albrecht and P. J. Steinhard ('82), ...

- Simplest realisation: Minimally coupled 'slowly rolling' scalar field ...

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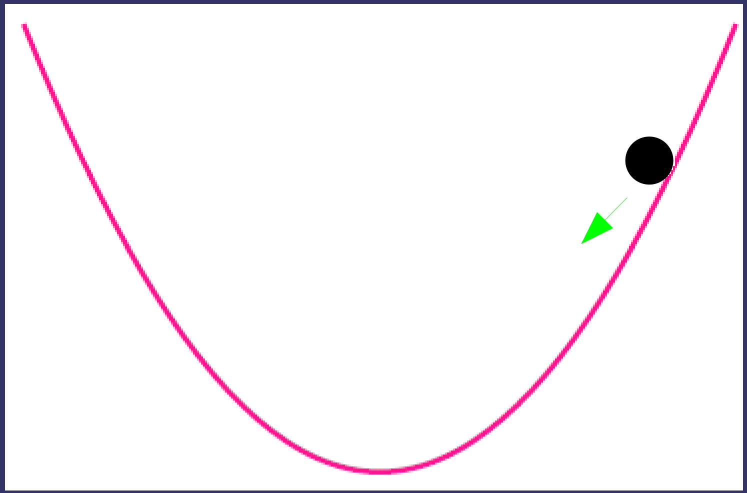
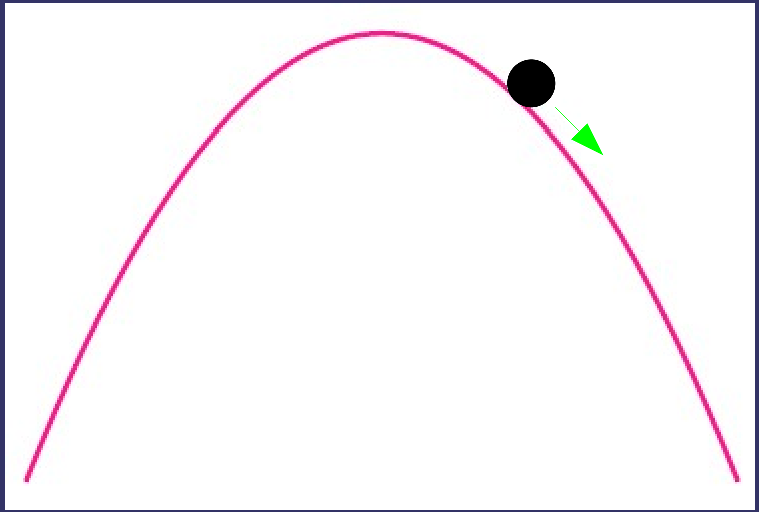
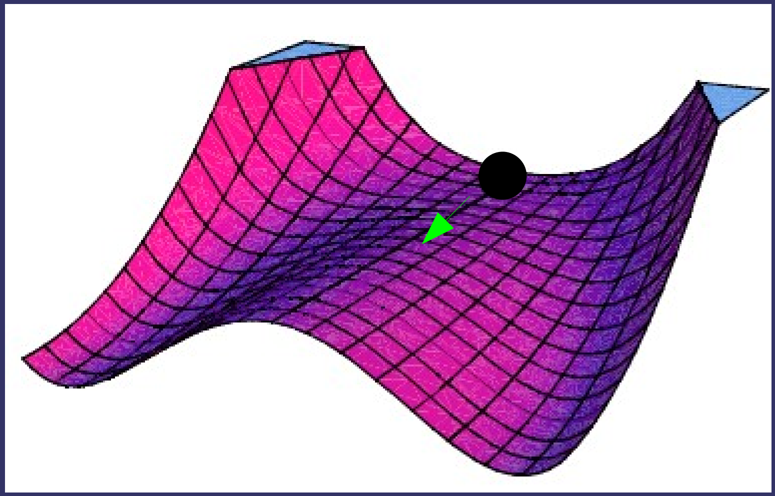
Types of inflation models (examples)



'Large field' (chaotic) inflation



'Small field' (new) inflation

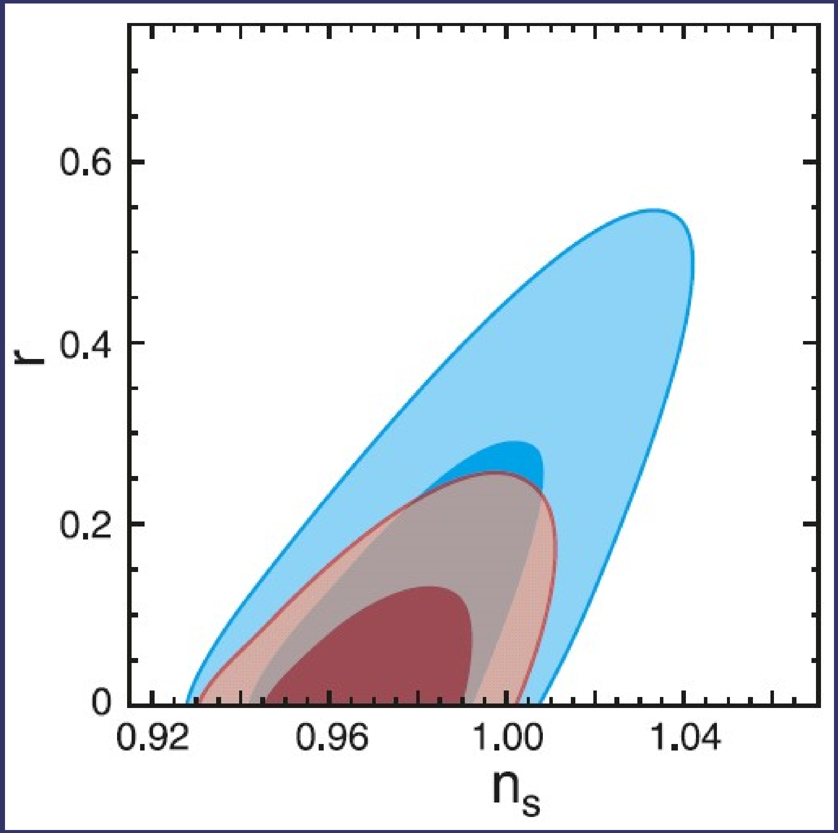


'Hybrid' inflation

... many variants of scalar field potentials can lead to inflation ...

Observations consistent with simplest slow roll inflationary models

- From WMAP 5-year data (+ SN + BAO):
  - Hints that $n_s < 1$:
    $$n_s = 0.960 \pm 0.013$$
  - No signs for gravitational waves:
    $$r < 0.22 \ (95\% \ \mathrm{CL})$$
  - Amplitude A_s (Cobe '92):
    $$A_s^{1/2} = 5.0\ (\pm 0.1) \cdot 10^{-5}$$
  - No clear signs for running of the spectral index
  - Compatible with adiabatic and Gaussian primordial perturbations



(WMAP '08,,
WMAP '08 + SN + BAO)

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Future: The PLANCK satellite

- PLANCK (launched on 14th of May 2009)
  - will measure n_s more precisely
    $\rightarrow$ Is n_s really $\neq 1$? Important prediction of inflation!
  - will be sensitive to r up to 0.01 ... 0.1
    $\rightarrow$ $r \neq 0$ would be smoking gun signal of inflation; results will help to discriminate between inflationary models
  - will more precisely test the adiabaticity and Gaussianity of the perturbations

    $\rightarrow$ Could rule out slow roll inflation by one single field (if deviations found)

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Inflation and models of particle physics

- ... often: Scalar field (= inflaton) is introduced 'ad hoc', without any connection to models of particle physics.

- Question:

  How is inflation connected to theories of particle physics ?

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A typical problem …

Inflation (typically taking place at high energies $\Lambda \sim M_{GUT}$)

new physics
@ Λ induces …

Hierarchy problem:
quantum corrections $\rightarrow$
$\delta m_H^2 \sim \Lambda^2$

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solution seems
to require ...

Supersymmetry
(as local symmetry: supergravity = SUGRA)

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seems to require ...

Supersymmetry (as local symmetry: supergravity = SUGRA)

SUGRA typically induces ...

Mass of the inflaton: $m_\phi \sim H \Rightarrow \eta \sim 1$

V(ϕ) from K & W:

$$V_F = e^K \left[K^{ij^*} \mathcal{D}_i W \mathcal{D}_{j^*} W^* - 3|W|^2 \right]$$

would spoil slow roll inflation!

η-problem of SUGRA inflation!

E.J Copeland, A.R. Liddle, D.H. Lyth, E.D. Stewart, D. Wands ('94)

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A typical problem ...

Inflation (typically taking place at high energies $\Lambda \sim M_{GUT}$)

new physics @ Λ induces ...

Hierarchy problem: quantum corrections $\rightarrow$ $\delta m_H^2 \sim \Lambda^2$

seems to require ...

Supersymmetry (as local symmetry: supergravity = SUGRA)

solve 'η-problem'

~~**Mass of the inflaton: $m_\phi \sim H \Rightarrow \eta \sim 1$**~~

Challenge: How can inflation be realised in supergravity theories?

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Possible solutions to the η-problem: 3 strategies

➲ **Expansion of K in fields/m_P:**

requires tuning of parameters

$$K = \sum_{i,j,k} \left(|X_i|^2 + \frac{\alpha_i}{M_P^2}|X_i|^4 + \frac{\beta_{ij}}{M_P^2}|X_i|^2|X_j|^2 + \mathcal{O}\left(\frac{|X_{i,j,k}|^6}{M_P^4}\right)\right)$$

➲ **'Shift' symmetry:** N -> N + i α

$\boxed{\text{K = f(N + N*)}}$

protects Im[N] from obtaining a SUGRA mass by symmetry!

(used by many authors ...)

➲ **'Heisenberg' symmetry:** $T \to T + \mathrm{i}\,\mu \qquad T \to T + \alpha^* N + |\alpha|^2/2 \qquad N \to N + \alpha$

$\boxed{\text{K = f}(\rho)}$ $\qquad \rho = T + T^* - |N|^2$

solves the η-problem for |N| by symmetry!

Gaillard, Murayama, Olive ('95)

T: 'modulus field', which has to be stabilised

Other possibility: 'D-term Hybrid inflation' (not discussed in this talk)

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Particle physics models of inflation in supergravity

- ... to illustrate/address both issues, let us look at the following example for a typical superpotential:

Schematically:

$$W = \kappa\, S\, (H^2 - M^2) + g(N,H))$$

Remark: Less simple potentials in practice! Also other possibilities ...

S: 'Driving field'
$|F_S|^2 \rightarrow$ **provides vacuum energy if <H>=0**

phase transition:
<H>=0 $\rightarrow$ <H>=M

H: Higgs field
<H>=0 (false vacuum)
<H>=M (true vacuum)

N: Matter field
i) get mass when <H>=M
ii) direct mass from W

Can S, H or N act as the inflaton field?

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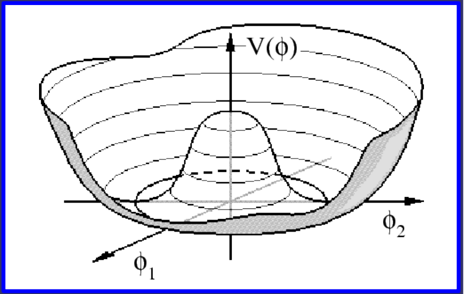
Particle physics models of inflation in supergravity

- In principle, any of the three types of fields can be the inflaton $\rightarrow$ link to particle physics!



$$W = \kappa\, S\, (H^2 - M^2) + g(N,H))$$

H: Higgs field
<H>=0 (false vacuum)
<H>=M (true vacuum)

'New Inflation'-type of model

Phase transition may be the one of

- **GUT symmetry breaking (however: monopole problem)** (inflation $\leftrightarrow$ GUTs: many works)
- **Flavour symmetry breaking (attractive: can be below GUT phase transition)**

S.A., S.F. King, M. Malinsky, L. Velasco-Sevilla, I. Zavala ('08)

(Remark: typically $H^2 \rightarrow f(H, \bar{H})$, with $\bar{H}$ in conjugate representation)

Particle physics models of inflation in supergravity

➲ In principle, any of the three types of fields can be the inflaton
$\rightarrow$ link to particle physics!

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'Hybrid Inflation'-type of model

(H = 'waterfall field' for ending inflation)

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Particle physics models of inflation in supergravity

- In principle, any of the three types of fields can be the inflaton
  $\rightarrow$ link to particle physics!

$m_\nu \sim v_{EW}^2/m_N$

$$W = \kappa S (H^2 - M^2) + g(N,H))$$

N: Matter field
i) get mass when <H>=M

Attractive candidate for N:

- **right-handed sneutrino = superpartner of ν_R from the seesaw mechanism**
  S.A., Bastero-Gil, King, Shafi ('04)
- **Phase transition (GUT, flavour, ...) gives its large mass after inflation**

new variant of 'Hybrid Inflation'

$\rightarrow$ *'Tribrid Inflation'*
(S for V_0, H ends inflation, N=inflaton)

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Particle physics models of inflation in supergravity

- In principle, any of the three types of fields can be the inflaton $\rightarrow$ link to particle physics!

$$W = \kappa\, \cancel{S\,(H^2 - M^2)} + g(N,H))$$

N: Matter field
i) direct mass from W

'Large field (chaotic)'-type of inflation model

Attractive candidate for N:

- **right-handed sneutrino = superpartner of n_R from the seesaw mechanism**
  Murayama, Suzuki, Yanagida, Yokoyama ('93)
- **for simplest superpotential $W = m_N\, N^2$, $m_N \sim 10^{13}$ GeV would be in the right range for seesaw and for inflation!**

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Solutions to the η-problem in classes of models

*) problems pointed out by
Brax et al ('06), Davis, Postma ('08)

	K expansion + tuning	Shift symmetry	Heisenberg symmetry
S is the inflaton ('Hybrid inflation')	(yes) Copeland et al; Dvali, Shafi, Schaefer ('94)	X*	X
H is the inflaton ('New inflation')	(yes) Shafi, Senoguz ('04)	X (?)	X (?)
New! N is the inflaton ('Tribrid inflation')	(yes) S.A. et al ('04)	yes S.A. et al ('09)	yes S.A. et al ('08)
Large field 'chaotic' inflation	X	yes Kawasaki et al ('00)	yes S.A. et al ('09)

Note: ... incomplete table!

'Tribrid inflation': New class of models; very suitable for solving the η-problem by symmetry! ... + other attractive features!

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Summary and Conclusions

picture from WMAP website

- Inflation solves flatness, horizon & monopole problems and it can provide the seed of $\delta T/T$ in the CMB and of structure in the universe
- Many open questions, for instance:
  - How is inflation linked to theories of particle physics? How can inflation be realised in supergravity theories?
- Attractive new class of inflation models in supergravity: “Tribrid Inflation'
- Temperture anisotropies of the CMB are a powerful probe of inflation ($\rightarrow$ PLANCK satellite)

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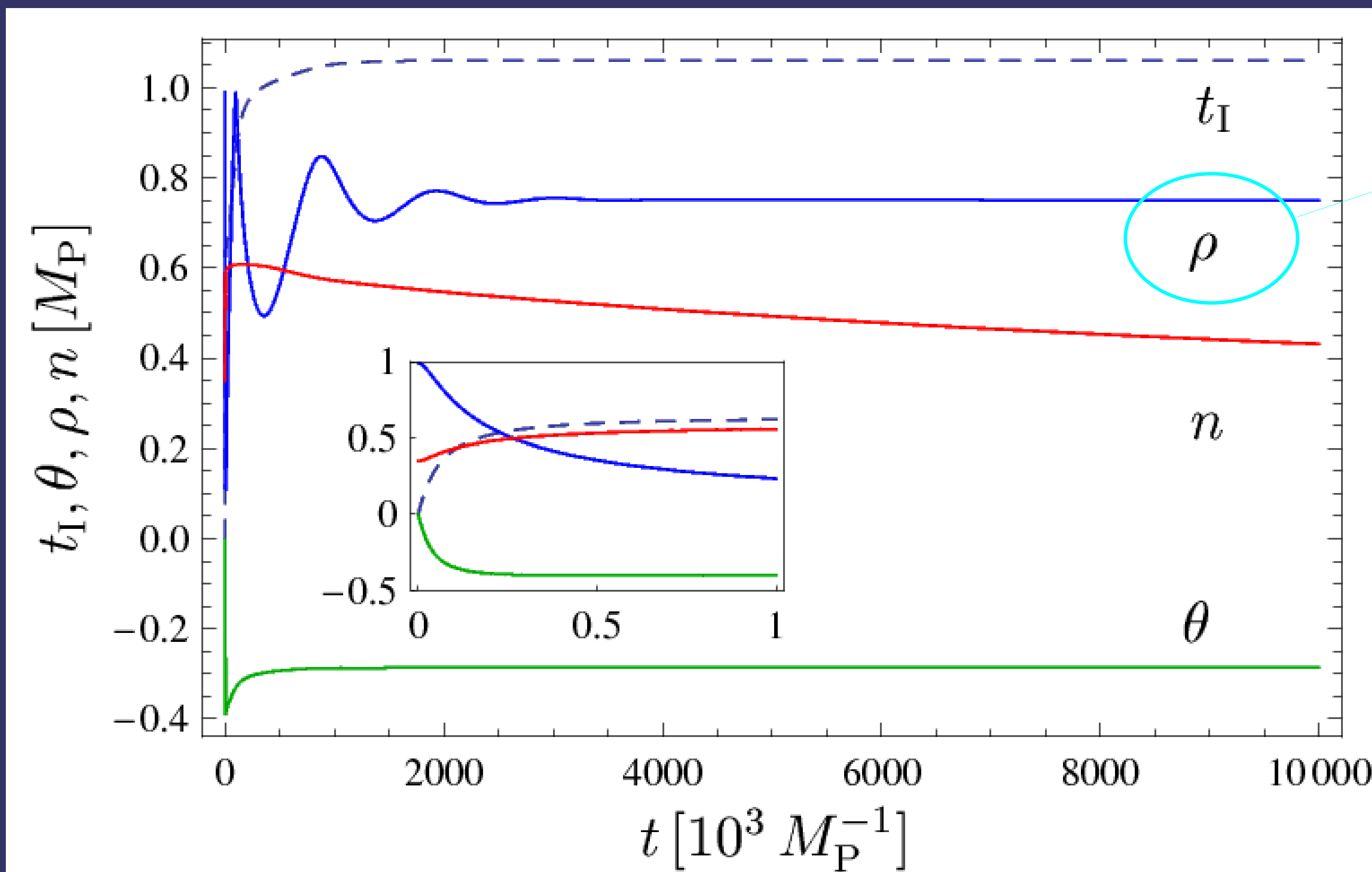
Important issue: Moduli stabilisation during inflation!

S.A., M. Basero-Gil, K. Dutta, S. F. King, P. M. Kostka ('08)



Modulus gets stabilised quickly with the help of the large vacuum energy during inflation!

Example: 'Tribrid inflation' + Heisenberg symmetry

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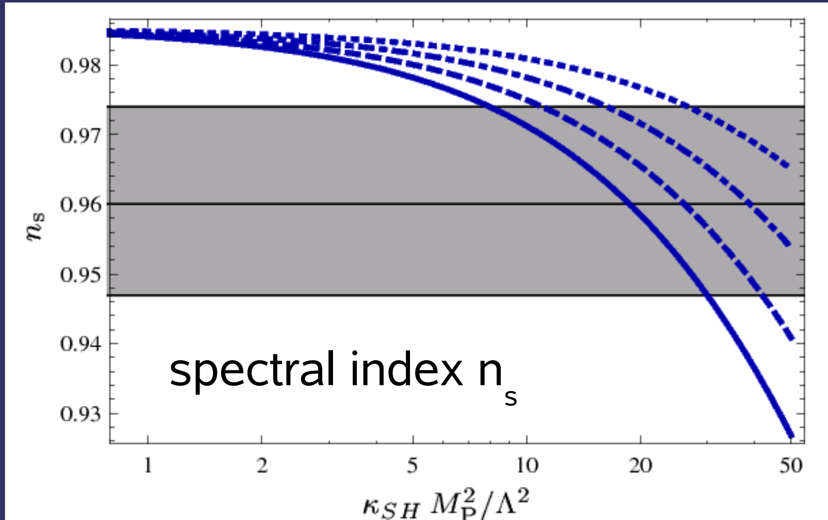
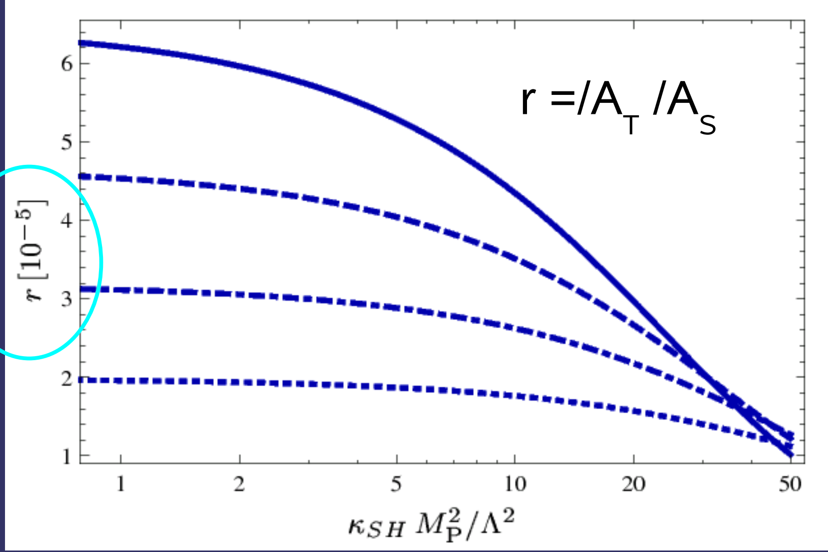
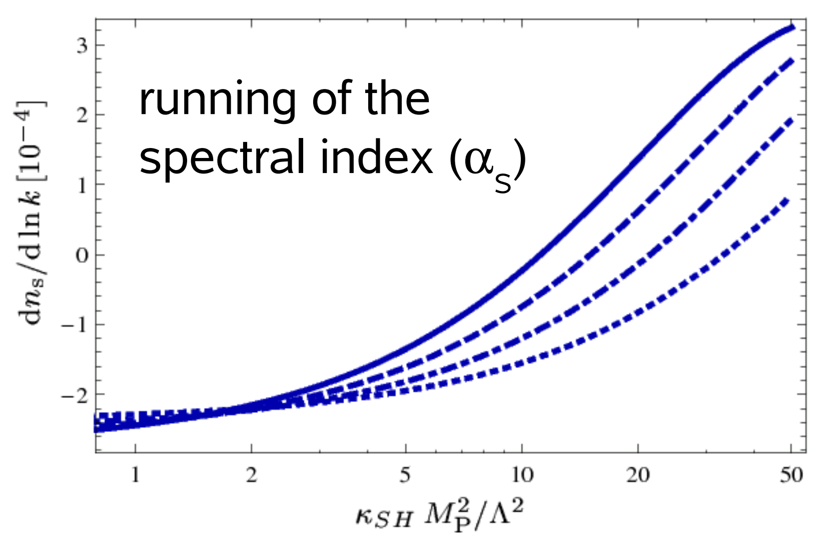
In an explicit model: calculation of the predictions ...

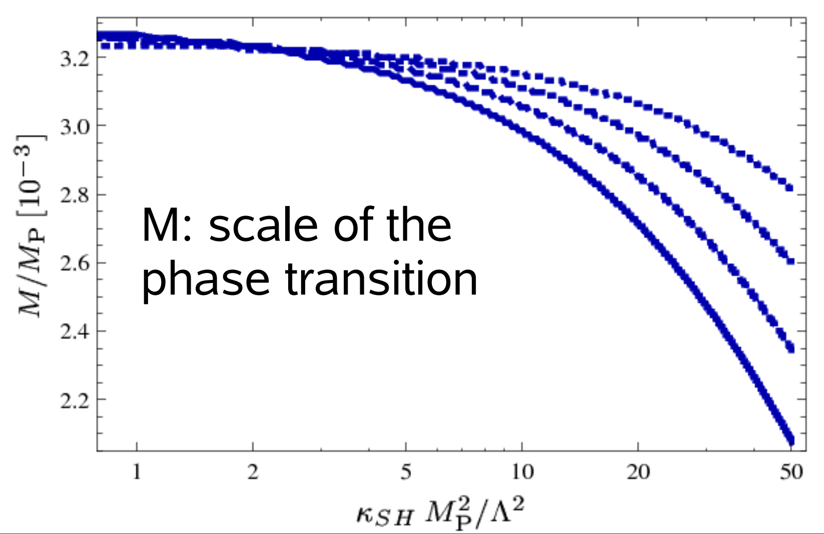
S.A., K. Dutta, P. M. Kostka ('09)





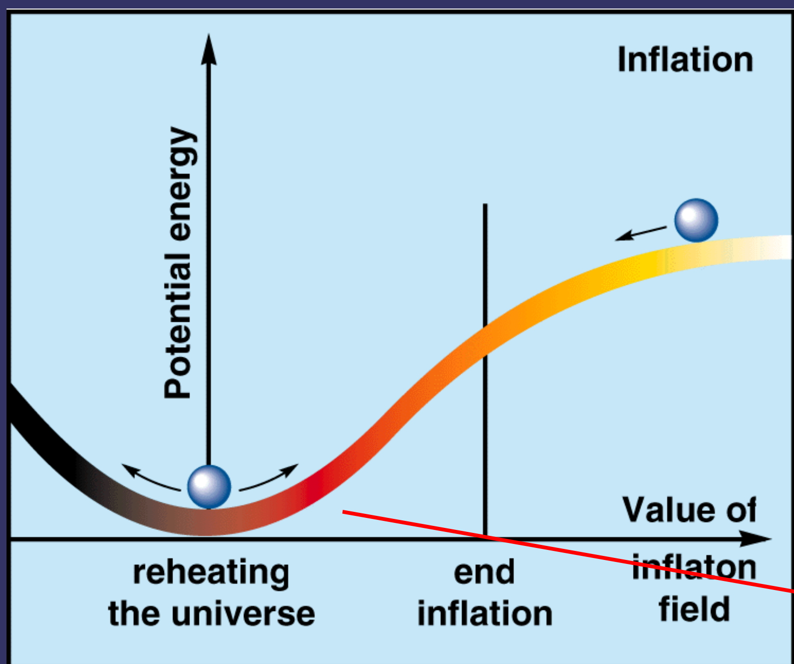
very small
(as typical for Hybrid models)





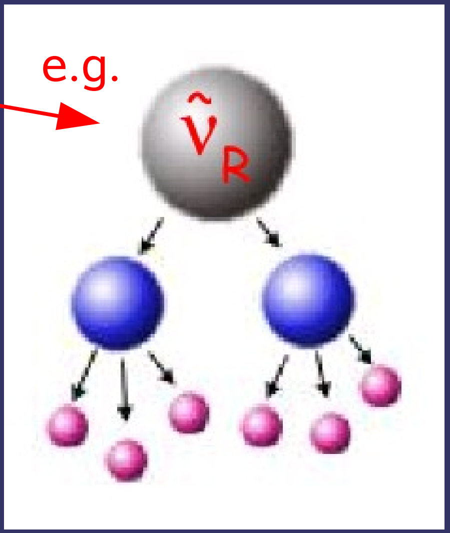
Example: 'Tribrid inflation' + shift symmetry

How can we test the link between particle physics and inflation?



In addition to the inflationary perturbations ↔ inflationary potential ...

Attractive possibility: very efficient leptogenesis after sneutrino inflation ...



Reheating?

Baryogenesis?

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