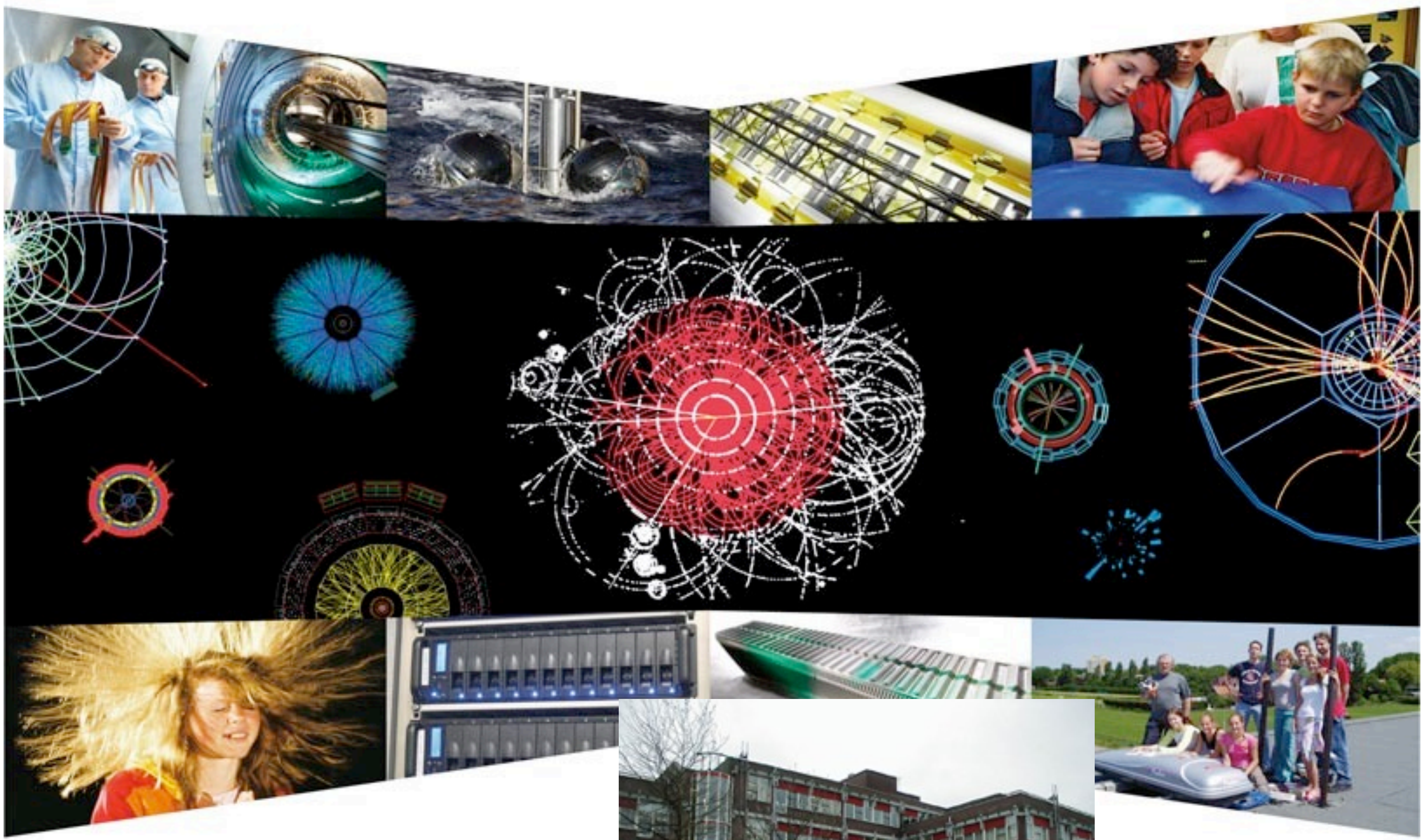
Moduli Stabilization in SUGRA Hybrid Inflation

Sander Mooij
Nikhef, Amsterdam
Supervisor: Marieke Postma

UniverseNet Lecce, September 14, 2010

Nikhef *(Nationaal Instituut voor Kern- en Hoge Energie Fysica)*



- www.nikhef.nl

Aim of the project (and the talk)

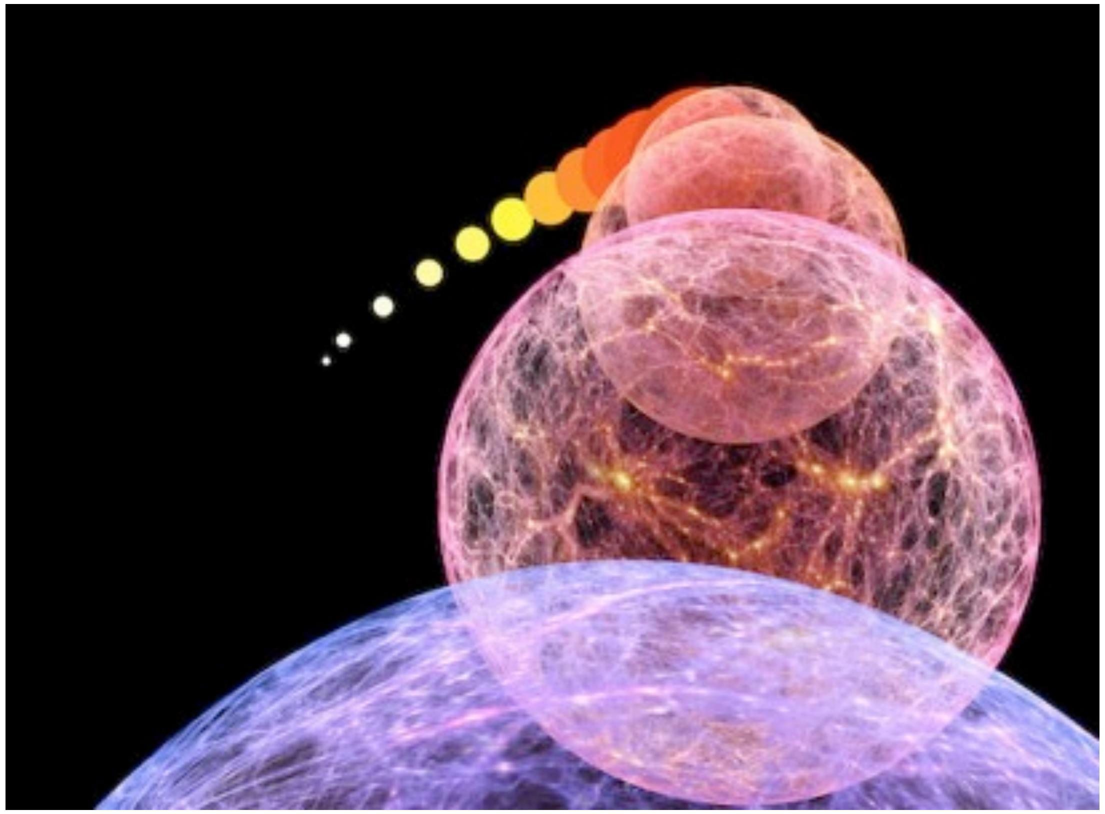
To add a moduli sector to a model of SUGRA hybrid inflation

Inflation

- Exponential explosion of the cosmological scale factor in the very early universe.

- Invented to solve the horizon problem, the flatness problem and the entropy problem of “Standard” Big Bang Theory.

- Provides seeds for structure formation.



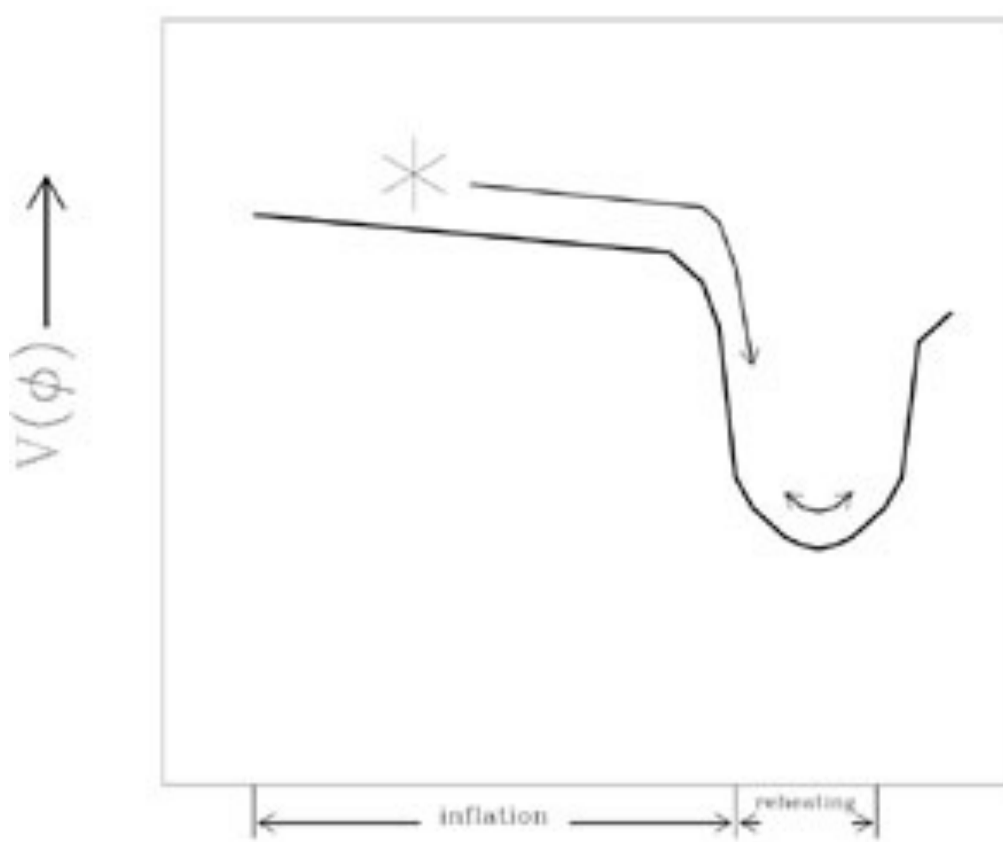
Inflation (II)

- Inflation can be generated by a scalar field rolling down an almost flat potential.

- (A flat potential guarantees negative equation of state, Friedmann equation then gives exponential solution for scale factor.)

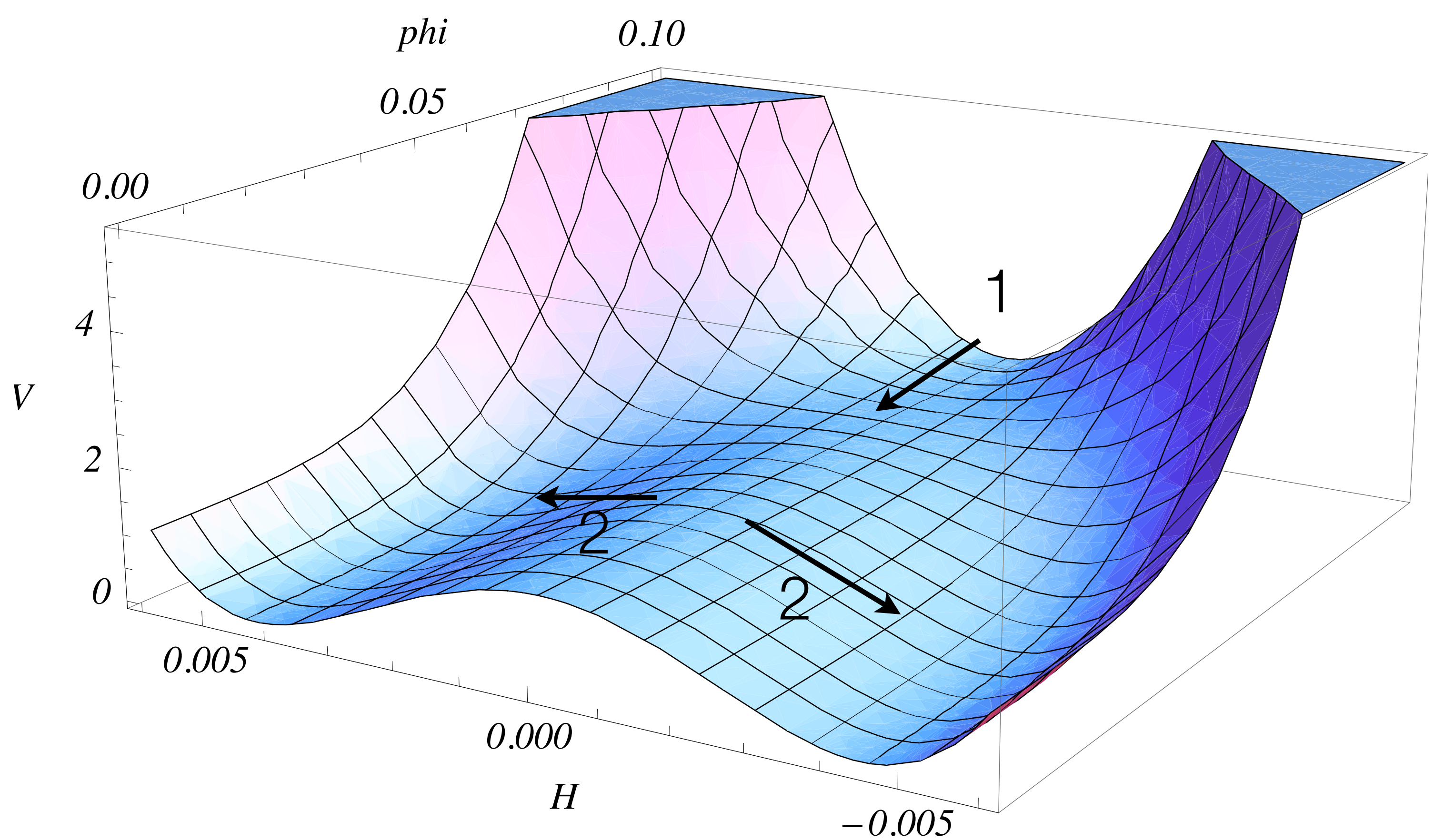
$$p = -\rho$$

- **So: how to get a scalar field in such a flat potential?**



Hybrid Inflation

- Hybrid inflation needs **two** fields: inflaton φ and waterfall H.
- During inflation (arrow 1) φ rolls down slowly while H is in its minimum at H=0. V>0.
- When φ crosses a critical value, H finds a minimum at H≠0 and inflation ends (arrow 2). V=0.



Supergravity (SUGRA)

- SUGRA is **local** supersymmetry (spacetime-dependent SUSY generators).

$$\hat{Q} \Rightarrow \hat{Q}(x^\mu)$$

- Any SUGRA theory is characterized by its **superpotential** W and **Kähler potential** K, which are functions of the superfields.

- Scalar (F-term) potential given by

$$V_F = e^K \left[D_i W K^{i\bar{j}} D_{\bar{j}} W^* - 3|W|^2 \right]$$

(i and j run over superfields)

$$D_i W \quad = \quad W_i + K_i W$$

(covariant derivative)

SUGRA hybrid inflation (Antusch, Dutta & Kostka - hep/ph 0902.2934)

- Model consisting of three superfields H, S and N that can be decomposed in real and imaginary parts. $H = H_R + iH_I \qquad S = S_R + iS_I \qquad N = N_R + iN_I$

- (Hope to connect N with neutrino superfield and H with GUT-scale Higgslike field.)

$$N \to N + i\mu$$

- At **tree level** the N_i field direction is flat thanks to a shift symmetry in K_inf. H_R acts as a waterfall field. All other fields find stable minima at 0.

$$V" > \frac{V}{3}$$

$$\begin{aligned} W_{\text{inf}} &= \kappa S\left(H^2 - M^2\right) + \frac{\lambda}{\Lambda} N^2 H^2 \\ K_{\text{inf}} &= |H|^2 + |S|^2 + \frac{1}{2}(N+N^*)^2 + \frac{\kappa_H}{\Lambda^2}|H|^4 + \frac{\kappa_S}{\Lambda^2}|S|^4 + \frac{\kappa_N}{4\,\Lambda^2}(N+N^*)^4 \\ &+ \frac{\kappa_{SH}}{\Lambda^2}|S|^2|H|^2 + \frac{\kappa_{SN}}{2\,\Lambda^2}|S|^2(N+N^*)^2 + \frac{\kappa_{HN}}{2\,\Lambda^2}|H|^2(N+N^*)^2 + \dots . \end{aligned}$$

SUGRA hybrid inflation (II)

- At **one-loop level** the N_i field direction gets slightly lifted by a Coleman-Weinberg loop effect.

- SUSY breaking term in W_inf causes mass split in H-multiplet:

$$m_{H_R}(N_I) + m_{H_I}(N_I) - 2m_{\tilde{H}}(N_I) \neq 0 \Rightarrow V_{CW}(N_I).$$

- **The resulting potential is suitable for hybrid slow-roll inflation.**

- **During** inflation $V_{\rm tree} = \kappa^2 M^4 \qquad H_R = H_I = N_R = S_R = S_I = 0$

- **After** inflation $V_{\rm tree} = 0 \qquad H_R = \pm M \qquad H_I = N_R = N_I = S_R = S_I = 0$

- All fields in stable minima during and after inflation.

- Large parameter window corresponding to correct CMB power spectrum and spectral index.

Moduli stabilization

- This model operates around the GUT-scale.
- If there is an underlying higher dimensional theory, we expect **moduli fields** to appear in the 4D effective action.
- Moduli fields parametrize sizes and shapes of suppressed extra dimensions.
  In the simplest case there is one moduli field to stabilize (volume modulus).
- **Can we add an extra moduli field T to the model without spoiling inflation?**

Adding the moduli section

We look for an extension of the model

$$W_{\text{inf}} \Rightarrow W_{\text{inf}} + W_{\text{mod}}$$

$$K_{\text{inf}} \Rightarrow K_{\text{inf}} + K_{\text{mod}}$$

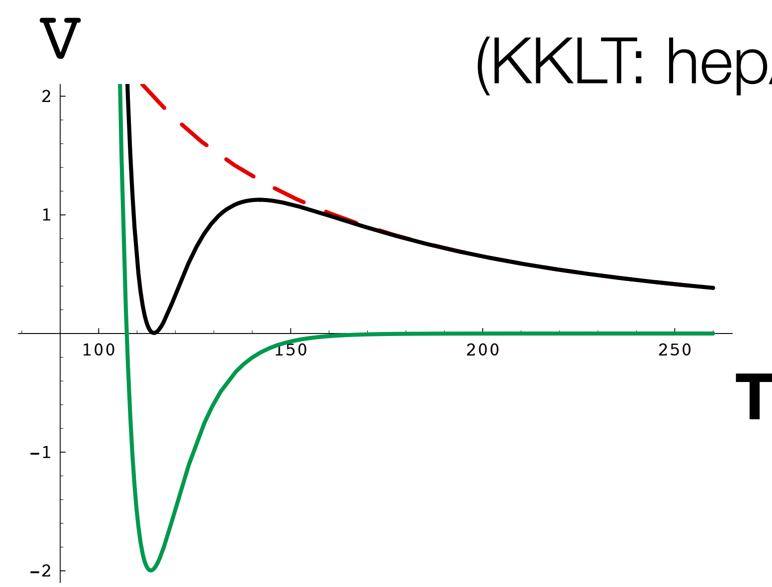
such that

- moduli field finds stable minimum
- inflaton field direction flat at tree level
- Coleman-Weinberg loop effect not spoiled
- waterfall mechanism still works
- after inflation V=0
- all other fields in stable minima during and after inflation
- model observables connect with CMB measurements

Moduli stabilization: first try

Most general (KKLT) approach from string theory:

$$W_{\mathrm{mod}} = -W_0 + Ae^{-aT}$$
$$K_{\mathrm{mod}} = -3\ln\left(T+\bar{T}\right)$$



(KKLT: hep/th 0301240)

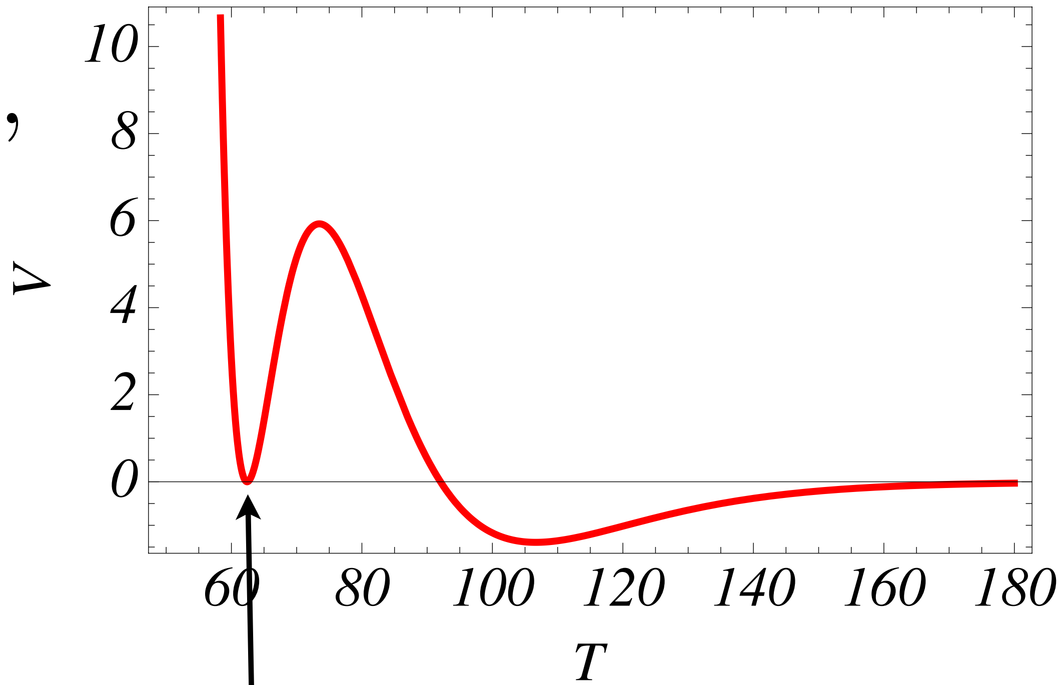
- Constant W_0 a priori free
- Small uplift (dashed red) of scalar potential needed to have V=0 after inflation.
  (Resulting potential in black.)
- Uplift breaks SUSY explicitly, therefore connection between SUSY breaking scale and inflation scale
- **PROBLEM: during inflation S-field finds nonzero minimum -> large extra contributions to H-masses -> no slow roll potential anymore**

Moduli stabilization in SUGRA hybrid inflation

(Mooij & Postma - hep/ph 1001.0664, JCAP 1006:012,2010)

We propose a next-to-simplest (KL) extension: (KL: hep/th 0411011)

$$W_{\rm mod} = -W_0 + Ae^{-aT} - Be^{-bT},$$
$$K_{\rm mod} = -3\ln\left(T+\bar{T}\right),$$



and find that if we tune W_0 such that W≈D_T W≈0 in the minimum of T, **all demands are fulfilled**.

$$W_0 = A\left(\frac{bB}{aA}\right)^{a/(a-b)} - B\left(\frac{bB}{aA}\right)^{b/(a-b)}$$

no uplift needed!

During $V_{\rm tree} = \frac{\kappa^2 M^4}{\sigma'^3}$ $T_R = \sigma$ $H_R = H_I = N_R = S_R = S_I = T_I = 0$

After $V_{\rm tree} = 0$ $H_R = \pm M$ $T_R = \sigma'$ $H_I = N_R = N_I = S_R = S_I = T_I = 0$

Moduli stabilization in SUGRA hybrid inflation (II)

(Mooij & Postma - hep/ph 1001.0664, JCAP 1006:012,2010)

- We find that if we can slightly perturb the tuned constant W_0 without spoiling inflation.

$$
\begin{aligned}
W_0 &\rightarrow W_0 + \epsilon_w \\
\epsilon_w &< 0.1 - 0.01\kappa M^2
\end{aligned}
$$

(corresponds to TeV-scale SUSY-breaking)

- So, at the cost of one extra exponent and one tuning, inflation works and the scales of SUSY breaking and inflation decouple.

Conclusions

- The SUGRA hybrid inflation model we consider is not compatible with the simplest moduli extension (KKLT).
- However, the next-to-simplest moduli extension (KL) can succesfully be added to the model.
- In this case, GUT-scale inflation can be combined with TeV-scale SUSY breaking.

smooij@nikhef.nl