O'KKLT at Finite T

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(collaboration with V. Calò)

Motivation

– Moduli stabilization:

Type IIA - fluxes enough (for geometric moduli)

Type IIB - fluxes and non-pert. (+ pert.) effects

Obtain AdS vacua

Lift to dS:

– anti-$D3$: explicit susy breaking...

– D-terms: hard to implement...

– use MDSB sector!

Heterotic - need $SU(3)$ str. manifolds

– MDSB:

- Susy breaking: want spontaneous SB

  Dynamical effects → natural hierachy btw fund. and SB scales

  DSB: very hard to find examples without global susy vacua

- Metastable vacua: hep-th/0602239 (ISS)

  Non-zero Witten index – not a problem

  Many examples, even SQCD!

  Use Seiberg dual: dynam. → tree-level

  Approx. ISS by O'Raifeartaigh model

→ Kallosh-Linde: O'KKLT model

  – 2 exp: reconcile standard inflation with light $m_{3/2}$

– Finite temperature:

Relevant for Early Universe

Why end up in a metastable vac.?

hep-th/0610334, hep-th/0611018:
Phase str. of ISS model at finite T

– start from a min. of V_T

– $T\downarrow$: phase transition

– roll towards a min. of V_0

$\Rightarrow$ Metast. vac. - thermodyn. preferred

What about KKLT with MDSB uplifting?

Phase structure of O'KKLT?

– $T \neq 0$: runaway or not?

– phase transitions?

Contents

O'KKLT model

– Basic ingredients:

KKLT with O'Raifeartaigh uplifting

$$W = W_{O'} + W_{KKLT}\,, \qquad K = K_{O'} + K_{KKLT}$$

- KKLT:

  $$W_{KKLT} = W_0 + Ae^{-a\rho} + Be^{-b\rho}$$

  $$K_{KKLT} = -3\ln(\rho + \bar{\rho})$$

- O'Raifeartaigh:

  heavy $\phi_{1,2}$ integrated out:

  $$W_{cl} = m\phi_1\phi_2 + \lambda S\phi_1^2 - \mu^2 S \qquad \rightarrow$$

  $$W_{O'} = -\mu^2 S\,, \qquad K_{O'} = S\bar{S} - \frac{(S\bar{S})^2}{\Lambda^2}$$

  $$\mu, \Lambda \ll 1$$

  2nd term in $K_{O'}$: 1-loop cor. for $|S| \ll 1$

– Minima:

$$V_0 = e^K \left(K^{A\bar{B}} D_A W D_{\bar{B}} \overline{W} - 3|W|^2 \right)$$

$$Im\rho = 0 \,,\; ImS = 0 \quad ; \quad Re\rho \equiv \sigma \,,\; ReS \equiv s$$

$$\frac{\partial V_0(\sigma, s)}{\partial s} = 0 \quad \longrightarrow \quad V_0(\sigma)\text{: complicated!}$$

$$V_0 = V_0^{(0)} + V_0^{(1)} s + V_0^{(2)} s^2 + \mathcal{O}(s^3)$$

- KKLT only:

  1 exp: 1 AdS minimum

  2 exp: 2 AdS minima

- O'KKLT:

  AdS $\longrightarrow$ dS

  1 exp: dS vac. with small V_0, only if $|W_0| \approx \mu^2$

  2 exp: no constraint

Field theory at finite T

– V_{eff}: (thermal equilibrium)

V_{eff} - quantum analogue of V_{tree}

Jackiw: functional methods derivation (at $T = 0$; Dolan-Jackiw: $T \neq 0$)

$\mathcal{L}(\{\chi^I\})$, $\{\chi^I\}$ - set of fields

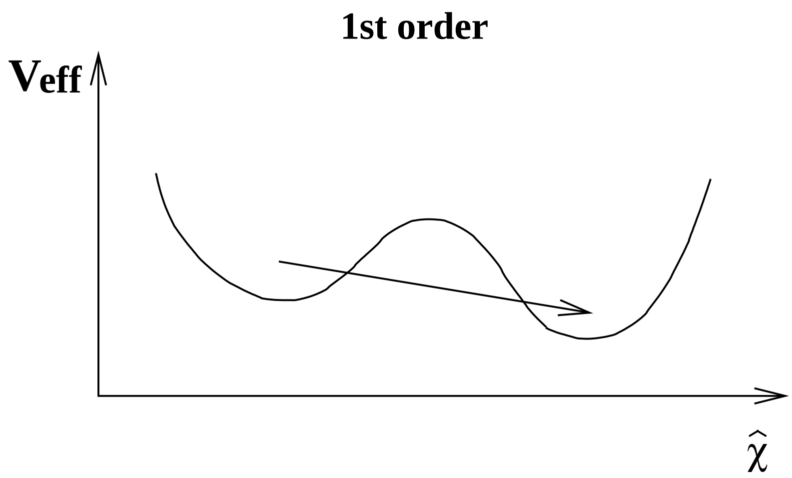
shift: $\chi^I \to \hat{\chi}^I + \chi^I$, $\hat{\chi}^I$ - const. bkgr.

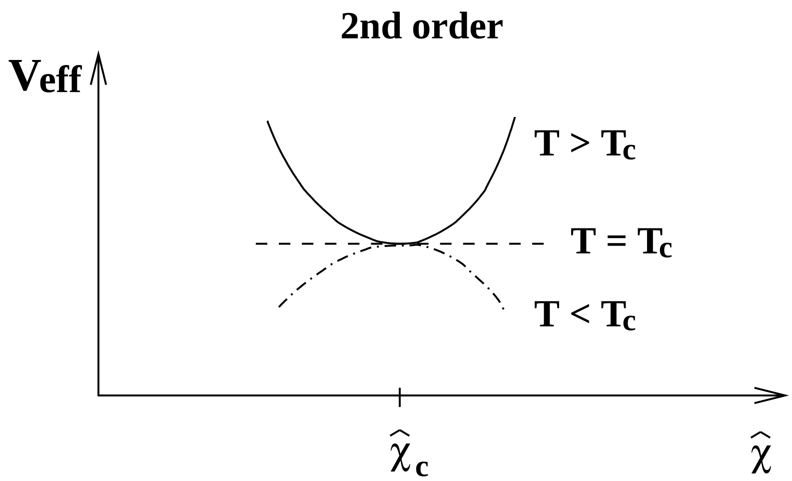
$$V_{eff}(\hat{\chi}) = V_{tree}(\hat{\chi}) + \underbrace{V_0^{(1l)}(\hat{\chi})}_{CW} + V_T^{(1l)}(\hat{\chi}) + \ldots,$$

$$V_T^{(1l)}(\hat{\chi}) = -\frac{\pi^2 T^4}{90}\left(g_b + \frac{7}{8} g_f\right) + \frac{T^2}{24}\left[\mathrm{Tr} M_s^2 + 3\mathrm{Tr} M_v^2 + \mathrm{Tr} M_f^2\right] + \ldots$$

→ high temperature expansion

– T_c for a phase transition:





2^{nd} order: $V'_{eff}(\hat{\chi}_c, T_c) = 0$, $V''_{eff}(\hat{\chi}_c, T_c) = 0$

- symmetry: $\hat{\chi} \to -\hat{\chi}$

$$T_c: \quad \frac{\partial^2 V_{eff}}{\partial \hat{\chi}^2}\Big|_{\hat{\chi}=0} = 0 \quad \Rightarrow \quad \frac{\partial^2 V_T}{\partial \hat{\chi}^2}\Big|_{\hat{\chi}=0} = -m^2$$

O'KKLT at finite T

Binetruy-Gaillard: generalized DJ for coupling to SUGRA

$$G = K + \ln|W|^2\,, \qquad V_0 = e^G\left(K^{A\bar{B}}G_A G_{\bar{B}} - 3\right)$$

$$\mathrm{Tr}M_f^2 = \langle e^G\left[K^{A\bar{B}}K^{C\bar{D}}R_{AC}R_{\bar{B}\bar{D}} - 2\right]\rangle,$$

$$R_{AC} \equiv \nabla_A G_C + G_A G_C\,, \qquad G_A \equiv \frac{\partial G}{\partial \chi^A}$$

$$\mathrm{Tr}M_b^2 = 2\,\langle K^{A\bar{B}}\frac{\partial^2 V_0}{\partial \chi^A \partial \bar{\chi}^{\bar{B}}}\rangle, \qquad A = \{\rho, S\}$$

$$\langle\rho\rangle = \langle\bar{\rho}\rangle = \sigma\,, \qquad \langle S\rangle = \langle\bar{S}\rangle = s$$

$$V_T = V_T^{(0)} + V_T^{(1)}s + V_T^{(2)}s^2 + \mathcal{O}(s^3)$$

Solutions of $\dfrac{\partial V_T^{(0)}(\sigma)}{\partial\sigma} = 0$ for finite ρ?

– One exponential:

$$\frac{\partial V_T^{(0)}(\sigma)}{\partial \sigma} = 0 \quad \text{is of form} \quad e^{cx} = F(x)\,,$$

$F(x)$ - ratio of polynomials and other exps

Analytic solutions unknown!

In principle, need numerical methods...

BUT, we prove that there is NO solution!

Method:

Use $\quad ns[e^x = F(x)] \leq 1 + ns[e^x = F'(x)]$,

$ns[Eq.]$ - number of solutions of $Eq.$

Recursion until reach a simple equation

Check that it does not have solutions

Essential that $|W_0| \approx \mu^2$

– Two exponentials:

Numerical cons. $\rightarrow$ $\exists$ finite-ρ min.

Essential parameters: B, W_0, μ, Λ, b/a

Define $x \equiv a\sigma$: $V_{0,T}(\sigma) \rightarrow V_{0,T}(x)$

B	$W_0 \times 10^4$	$x_{dS}^{(0)}$	$x_{min}^{(T)}$	$x_{AdS}^{(0)}$
−1.040	−0.76	4.88	5.62	7.84
−1.036	−1.1	4.50	5.25	7.40
−1.032	−1.64	4.11	4.83	6.92
−1.028	−2.4	3.73	4.44	6.44
−1.024	−3.533	3.34	4.04	6.00
−1.020	−5.21	2.96	3.64	5.52
−1.016	−7.67	2.55	3.20	5.02

Can choose a, so that $\sigma_{dS} \sim \mathcal{O}(100)$

Note:

Discrete changes of sets of param.,

Impl. for Weinberg's argument?...

Original goal:

$\longrightarrow$ start from V_T min.

$\longrightarrow$ roll towards dS or AdS min. of V_0?

However, always find $T_c \sim 0.1 M_P$

But SUGRA approx. good for $T \ll M_P$

- Interpretation:

  $\forall\, T \ll M_P$ system is in $T = 0$ dS min.

  O'KKLT: early Universe after inflation

  - At end of inflation: $T = 0$
  - Exit: reheating to some finite T

  Reheating doesn't destab. dS vacuum!

– One exponential revisited:
(recall: $|W_0| \approx \mu^2$)

Extrema of V_{eff} at $T \neq 0$ det. by V_0?

Not always:

$$\frac{|V_T|}{|V_0|}\Big|_{x=x_{dS}} \approx \left(\mathcal{O}(1)\,\frac{1}{\Lambda^2} + \mathcal{O}(1)\,x_{dS}^2\right)\frac{T^2}{3}$$

x_{dS} - determined by μ ; $\mu, \Lambda \ll 1$

Largest $\mu \;\rightarrow\; x_{dS} \sim \mathcal{O}(10)$; $\mu\downarrow \;\rightarrow\; x_{dS}\uparrow$

- 1st term dominates: $x_{dS} \sim \mathcal{O}(10)$

  V_0 dS min. persists for $T < \Lambda$

- 2nd term dominates: $x_{dS} \sim \mathcal{O}(10^3)$

  V_0 dS min. persists for $T < x_{dS}^{-1}$

In general: $T_c \ll M_P$, $T > T_c$: runaway

Summary

- O'KKLT at finite T:
  - 1 exp: $V_T(\rho)$ - runaway
  - 2 exp: $\exists$ finite-ρ min. of V_T
  - dS min. of V_0:
    - 2 exp: Not destab. by therm. cor.
    - 1 exp: $\exists\, T_c \ll M_P$; $T > T_c$ - runaway

- Open issues:
  - Understand discrete param. values
  - Dynamical (non-equil.) effects
  - Phase structure of LVC (BBCQ)
  - Non-geometric compact. (BBVW)