Hubble-induced mass from MSSM plasma

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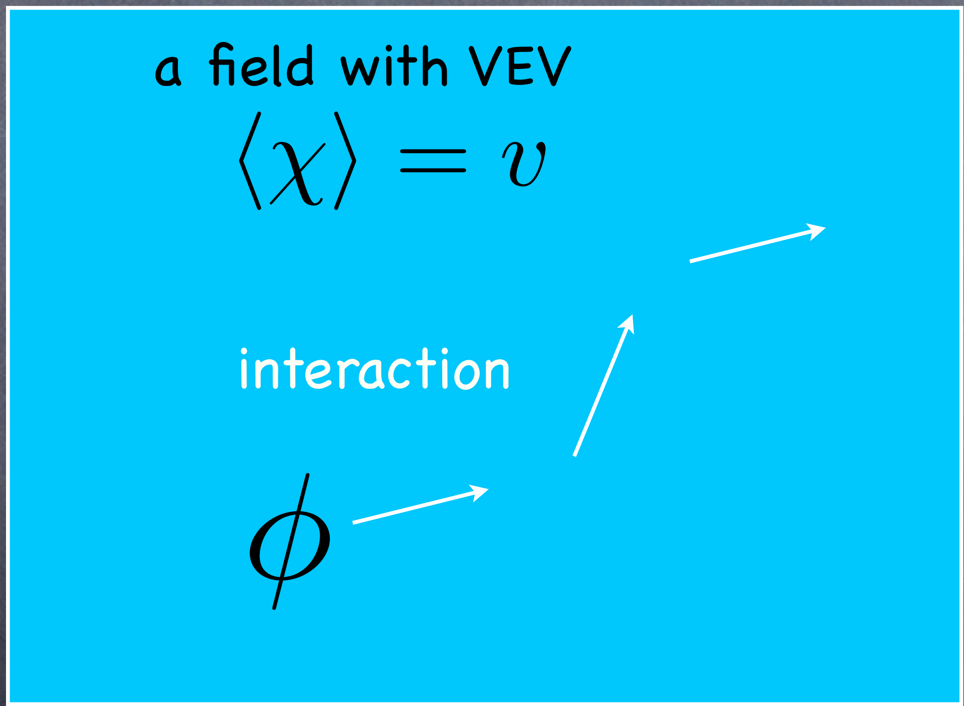
keywords

- effective mass
- thermal effect

effective mass

In the very early universe, it is possible that some fields have VEV and generate "effective masses".



effective mass

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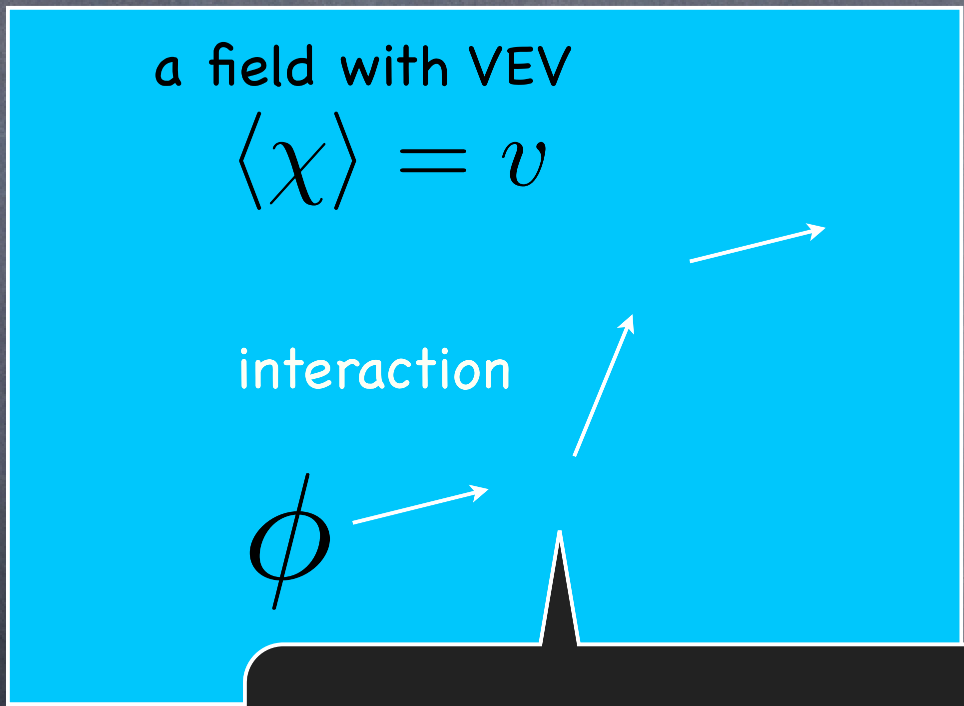

the effective mass $\tilde{m}_\phi = yv$

the Hubble-induced mass in inflationary era

B.A.Ovrut, P.J.Steinhardt (1983)
M.Dine, W.Fischler, D.Nemeschansky (1984)
G.D.Coughlan, R.Holman,P.Ramond, G.G.Ross (1984)
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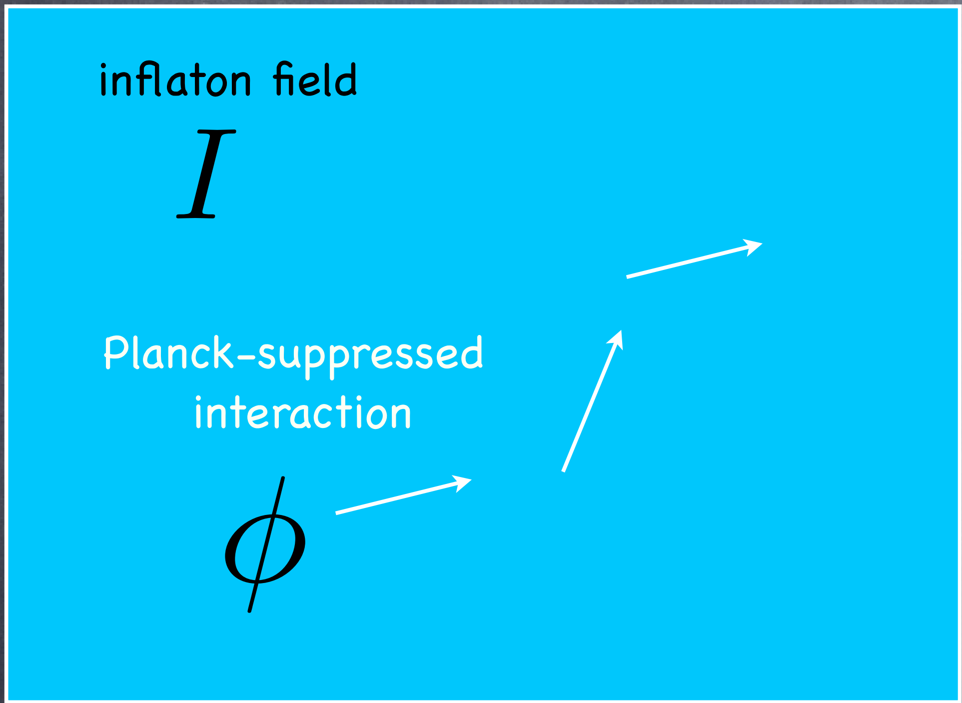

$$V \supset \frac{|\phi|^2}{M_{\rm P}^2}\rho_I = 3H_I^2|\phi|^2.$$

supergravity correction

the Hubble-induced mass in inflationary era

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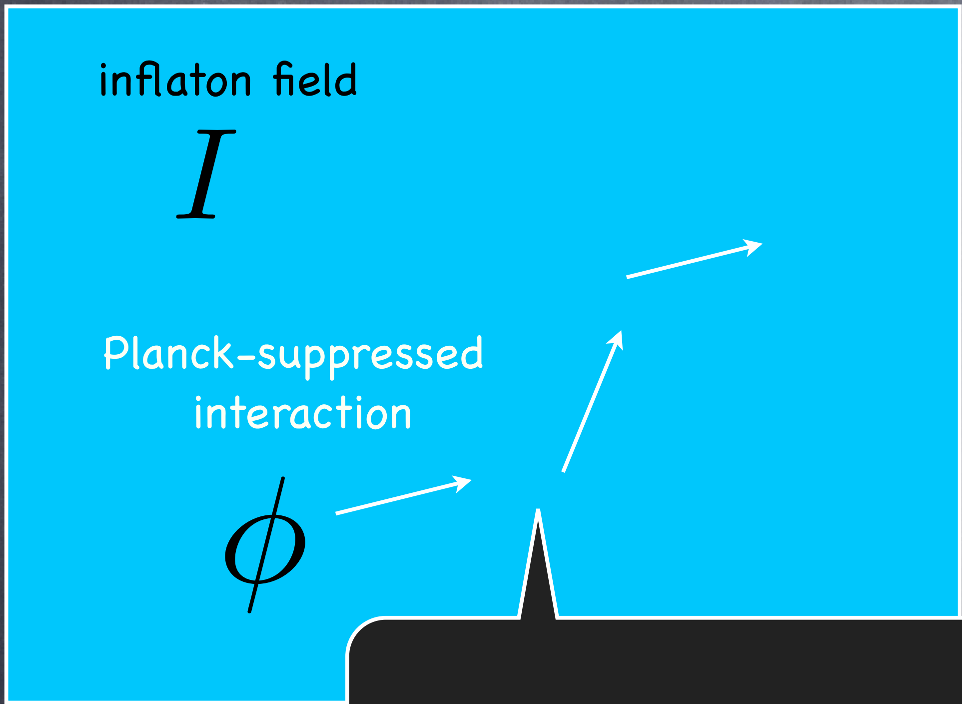

the effective mass $\tilde{m}_\phi \simeq H$

$$V \supset \frac{|\phi|^2}{M_{\rm P}^2}\rho_I = 3H_I^2|\phi|^2.$$

supergravity correction

"the Hubble-induced mass"

the importance of the Hubble-induced mass in the inflaton dominated era

- The Affleck-Dine baryogenesis

  I.Affleck, M.Dine (1985); M.Dine et al (1995)

- The adiabatic solution for the cosmological moduli problem

  A.D.Linde (1996); K.Nakayama et al (2011)

- The curvaton model (in supergravity)

the importance of the Hubble-induced mass in the inflaton dominated era

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↓

in RD era ???

- thermal effects in cosmology
  - dispersion relation is modified
  - dissipation occurs
  - symmetry preservation

  and so on

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2. Motivation
3. Strategy
4. Results
5. Conclusions

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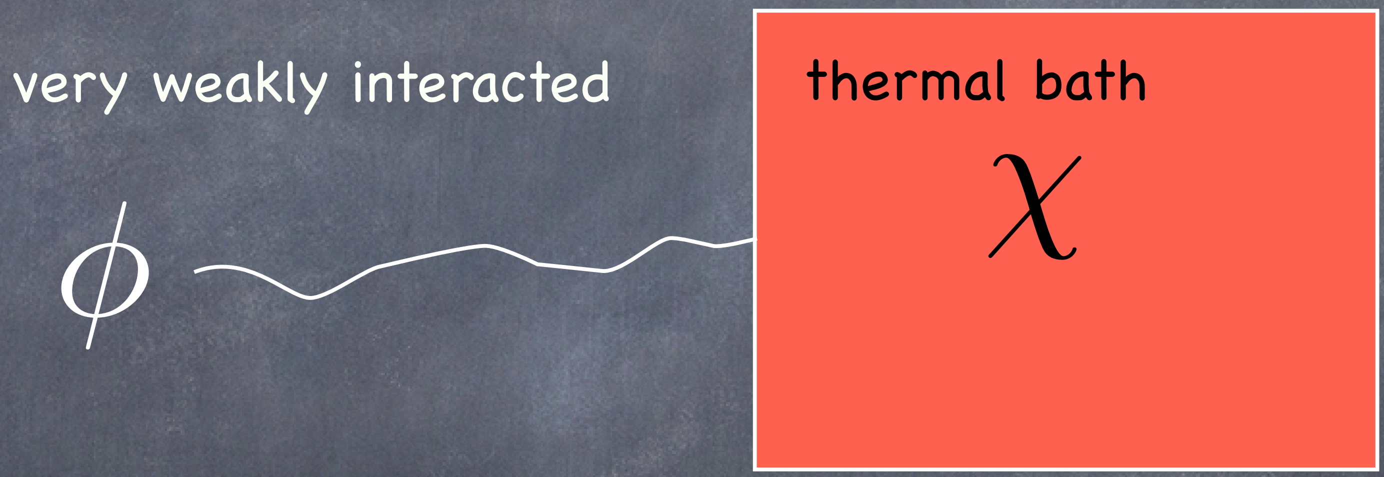
- an effective mass in the RD era ?



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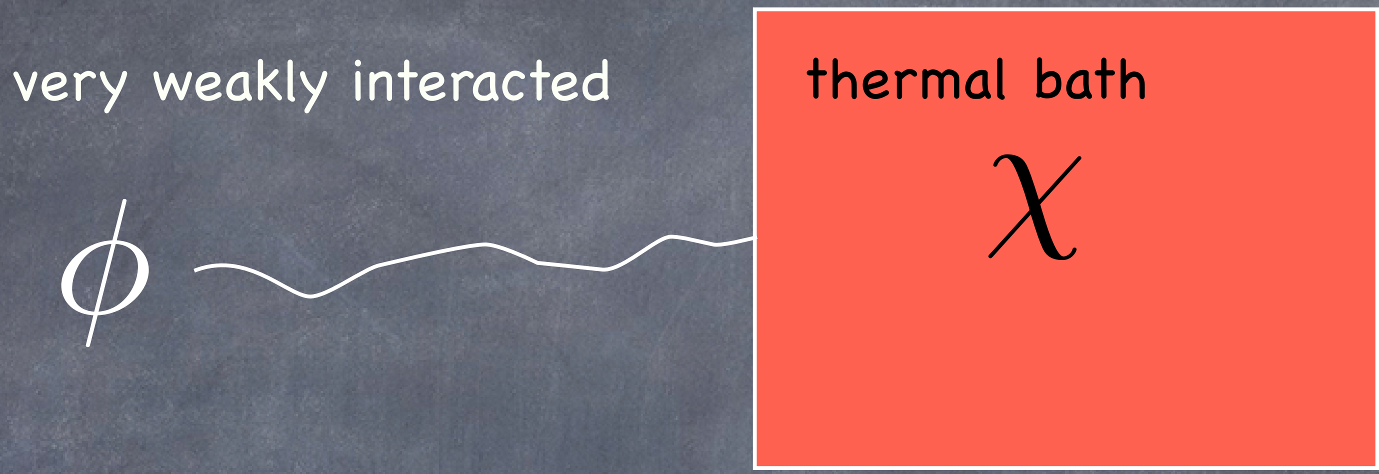


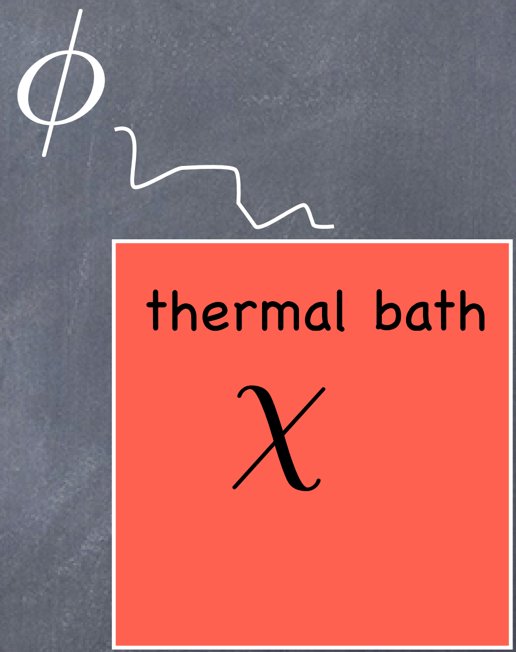
$$m_\phi = m_0^2 + \cancel{g^2T^2} + \cdots$$

an effective mass in the RD era ?

T.Asaka, M.Kawasaki and M.Yamaguchi (1999)

D.Lyth and T.Moroi (2004)

$$\mathcal{L}^{\chi}_{\rm kin.} = \left(1 + c\frac{|\phi|^2}{M_{\rm P}^2}\right)\partial_\mu \chi^* \partial^\mu \chi$$



$$\Rightarrow \quad \tilde{m}_\phi^2 = -\frac{c}{M_{\rm P}^2}\langle \partial_\mu \chi^* \partial^\mu \chi \rangle_{\rm th}$$

$$= ???$$

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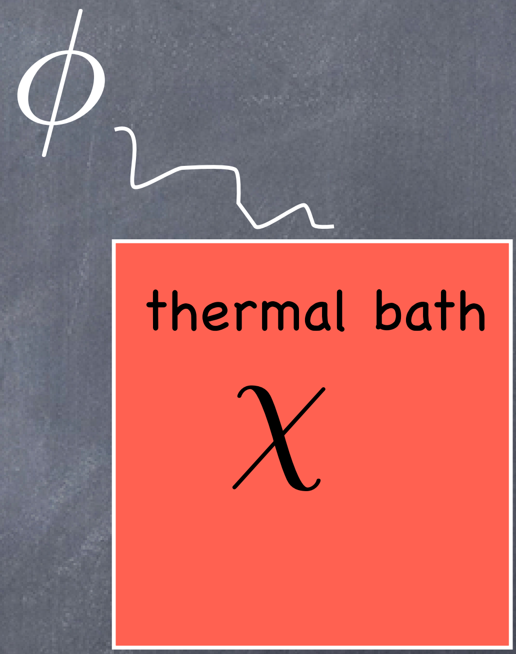

$$\Rightarrow \quad \tilde{m}_\phi^2 = -\frac{c}{M_{\rm P}^2} \langle \partial_\mu \chi^* \partial^\mu \chi \rangle_{\rm th}$$

$$=???$$

- equation of motion ?
- field expansion ?

- an effective mass in the RD era ?

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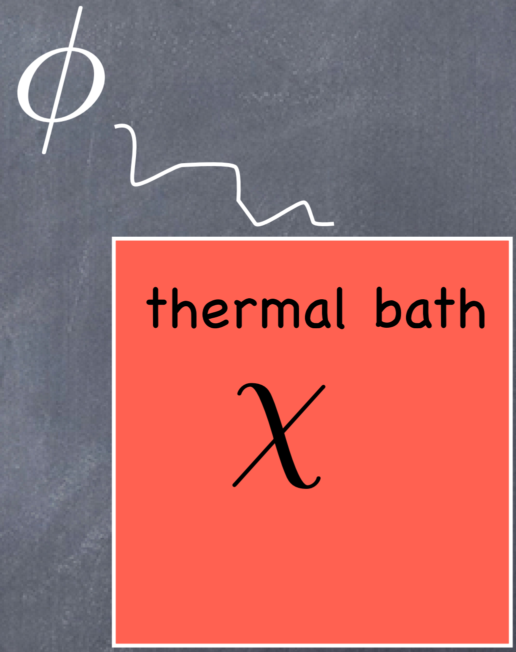

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$$=???$$

Thermal Field Theory

Contents

- the strategy of this work

$$K = |\phi|^2 + |\chi|^2 + c\frac{|\phi|^2|\chi|^2}{M_{\rm P}^2}$$

$$W = \frac{y}{3!}\chi^3$$

We obtain the following kinetic term and scalar potential:

$$\mathcal{L}_{\rm kin.}^{\chi} = \underline{\left(1 + \frac{c|\phi|^2}{M_{\rm P}^2}\right)} \partial_\mu \chi^* \partial^\mu \chi$$

$$V_F = \underline{\left(1 + \frac{(1-c)|\phi|^2}{M_{\rm P}^2}\right)} \frac{y^2}{4}(|\chi|^2)^2 + \mathcal{O}(M_{\rm P}^{-4})$$

supergravity effects

the strategy of this work

Using the rescaled field: $\hat{\chi} = \left(1 + \frac{c|\phi|^2}{M_{\rm P}^2}\right)^{1/2} \chi$

$$\mathcal{L}^{\chi}_{\rm kin.} = \partial_\mu \hat{\chi}^* \partial^\mu \hat{\chi}$$

$$V_F = \frac{\hat{y}^2}{4}(|\hat{\chi}|^2)^2 + \mathcal{O}(M_{\rm P}^{-4})$$

Now, all the supergravity effects are absorbed into the rescaled yukawa coupling :

$$\hat{y}^2 = y^2 \left(1 + \frac{(1-3c)|\phi|^2}{M_{\rm P}^2}\right)$$

- the strategy of this work

kinetic terms
interaction terms

couplings

supergravity effects
(ϕ -dependence)

- the strategy of this work

chiral fields rescaling

kinetic terms
interaction terms

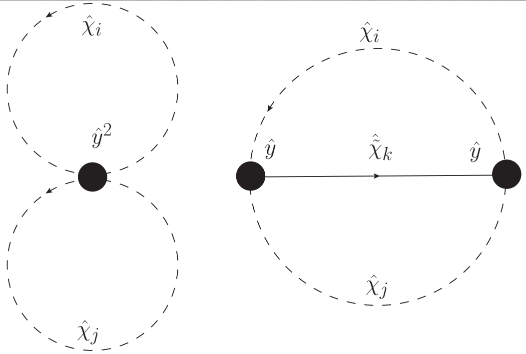
couplings

supergravity effects
(ϕ -dependence)

the strategy of this work

The free energy

$$\Omega_2 = \frac{\hat{y}^2 T^4}{288} = \frac{y^2 T^4}{288} - \frac{(c - 1/3) y^2 |\phi|^2}{96} \frac{T^4}{M_{\rm P}^2}$$



From this, we can read off the effective mass-squared:

$$\tilde{m}_\phi^2 = -\frac{c - 1/3}{96} \frac{y^2 T^4}{M_{\rm P}^2}$$

$$= -\frac{c - 1/3}{244\pi^2} y^2 H^2$$

the strategy of this work

The free energy

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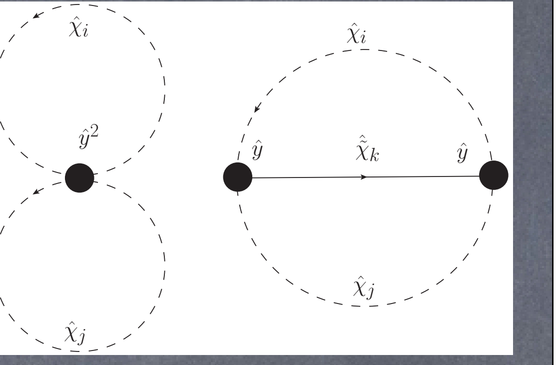

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In summary,

> in order to read off the effective mass-squared, we need only to evaluate the free energy with the rescaled couplings.

the strategy of this work

The gauge couplings are not affected by the field rescaling at the classical level:

$$\mathcal{L}^{\chi}_{\mathrm{kin.}} = \left(1 + \frac{c|\phi|^2}{M_{\mathrm{P}}^2}\right) D_\mu \chi^* D^\mu \chi = D_\mu \hat{\chi}^* D^\mu \hat{\chi}$$

However, the same rescaling induces the rescaling anomaly:

K.Konishi, K.Shizuya (1985)
N.Arkani-Hamed, H.Murayama (2000)

$$\prod_i \mathcal{D}\chi_i \mathcal{D}\chi_i^\dagger = \prod_i \mathcal{D}\hat{\chi}_i \mathcal{D}\hat{\chi}_i{}^\dagger \exp\left\{ i \int \mathrm{d}^4 x \sum_i \frac{-1}{16} \int \mathrm{d}^2\theta \, \frac{t_2(\chi_i)}{8\pi^2} \frac{c_i|\phi|^2}{M_{\mathrm{P}}^2} W_\alpha(V_h) W^\alpha(V_h) + h.c. \right\}$$

→ the rescaling gauge coupling

Contents

MSSM plasma contributions

$$K = |\phi|^2 + \sum_i \left(1 + \frac{c_i|\phi|^2}{M_{\rm P}^2}\right) \chi_i^\dagger e^{2gV} \chi_i$$

$$W_{\rm MSSM} = y_t \bar{t}_R (t_L H_u^0 - b_L H_u^+) + y_b \bar{b}_R (b_L H_d^0 - t_L H_d^-) \\ + y_\tau \bar{\tau}_R (\tau_L H_d^0 - \nu_\tau H_d^-)$$

M.Kawasaki, F.Takahashi, T.T (2012)

$$\tilde{m}_\phi^2 = \tilde{m}_\phi^2|_{\rm yukawa} + \tilde{m}_\phi^2|_{\rm gauge} \\ = \left\{ -\frac{81}{61\pi} \sum_{i=t,b,\tau} \gamma_i \left(\bar{c}_i - \frac{1}{3}\right) \alpha_{y_i} + \frac{756}{61\pi^2} \bar{c}_s \alpha_s^2 + \frac{1449}{244\pi^2} \bar{c}_2 \alpha_2^2 + \frac{1089}{244\pi^2} \bar{c}_Y \alpha_Y^2 \right\} H^2$$

"Hubble-induced mass"

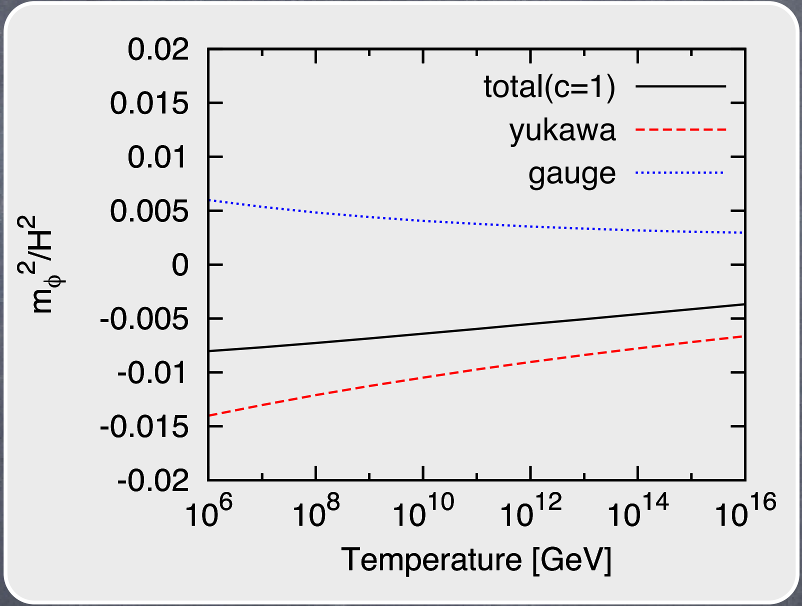
$$\gamma_t = \gamma_b = 1, \ \gamma_\tau = \frac{1}{3}$$

$$\alpha_{y_i} = \frac{y_i^2}{4\pi}$$

results

M.Kawasaki, F.Takahashi, T.T (2012)

the temperature dependence with typical parameter sets



all the coefficients c_i = 1

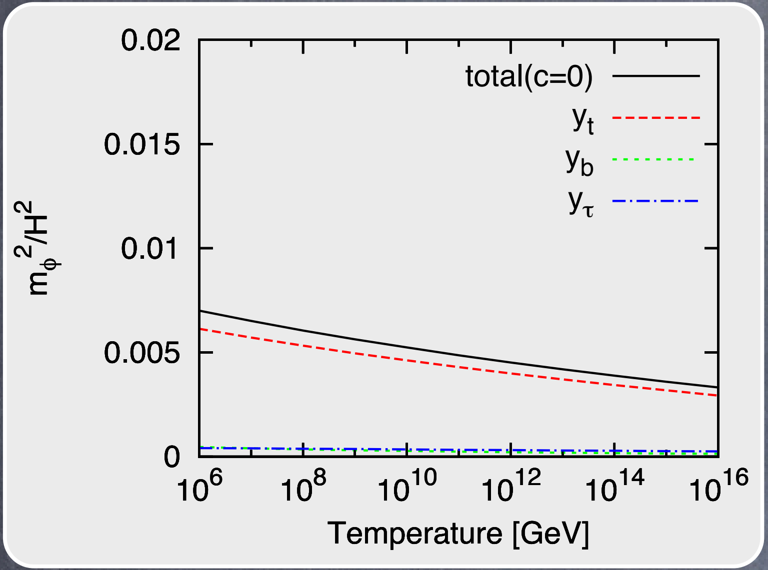
sparticle masses are O(1-10TeV)

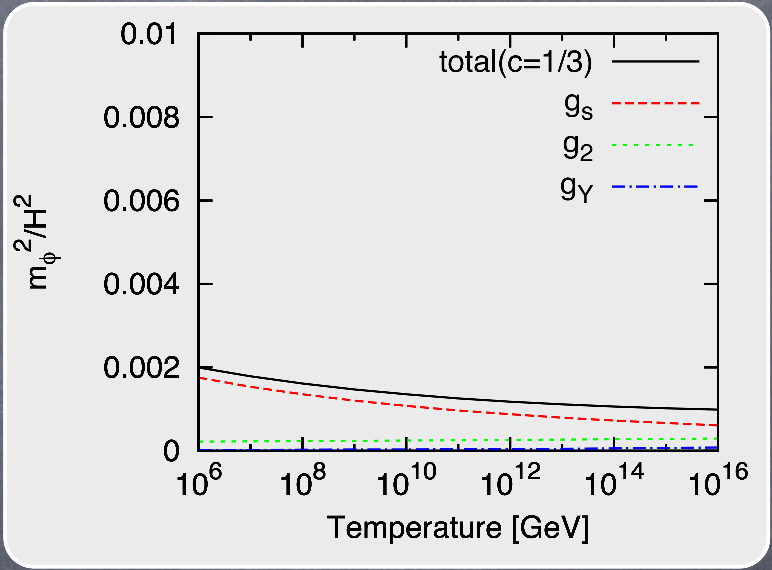
Numerically, we find

$$|\tilde{m}_\phi^2| \sim 10^{-2} H^2$$

results

M.Kawasaki, F.Takahashi, T.Takesako (2012)





all the coefficients c_i = 0
(all the gauge coupling contributions vanish)

all the coefficients c_i = 1/3
(all the yukawa coupling contributions vanish)

$$|\tilde{m}_\phi^2| \sim 10^{-2} - 10^{-3} H^2$$

$$|\tilde{m}_\phi^2| \sim 10^{-3} H^2$$

Implicaltions of our findings in the RD era

$$|\tilde{m}_\phi^2| \sim 10^{-2} - 10^{-3} H^2$$

- The Affleck-Dine baryogenesis
- The adiabatic solution for the cosmological moduli problem
- The curvaton model (in supergravity)

Implicaltions of our findings in the RD era

$$|\tilde{m}_\phi^2| \sim 10^{-2} - 10^{-3} H^2$$

- The Affleck-Dine baryogenesis — useless
- The adiabatic solution for the cosmological moduli problem — useless
- The curvaton model (in supergravity) — good news

conclusions

- In this work, we at first time show the transparent procedure for the analysis of the Hubble-induced mass arising from the MSSM thermal bath.

- We obtain the complete expression for the Hubble-induced mass from the MSSM plasma at leading order in the gauge and yukawa couplings.

- Numerically, we find

$$|\tilde{m}_\phi^2| \sim 10^{-2} - 10^{-3} H^2$$

for typical parameter sets

Thank you!

- the supergravity effects

for scalar fields

$$V_F = \mathrm{e}^{K/M_\mathrm{P}^2}\left\{ D_i W K^{i\bar{j}} \overline{D_j W} - \frac{3|W|^2}{M_\mathrm{P}^2} \right\}$$

$$\mathcal{L}_{\mathrm{kin.}} = K_{i\bar{j}} \partial_\mu \chi_i^* \partial^\mu \chi_j$$

supergravity corrections