Dissipative effects on MSSM inflation

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Kohei Kamada
(RESCEU,The University of Tokyo,Japan)
Collaboration with Jun'ichi Yokoyama

Introduction

- Inflation(Guth, Sato('81))

  Solution of many cosmological problems

  WMAP results strongly support inflation.

- MSSM (Minimal Supersymmetric Standard Model)flat direction

  Possible candidate for inflaton

  (MSSM inflation;Allahverdi et. al. ('06))

  no need for extra fields beyond MSSM

  Severe fine-tuning of potential and initial condition

⇒ Can interactions with other fields help these difficulties?

MSSM inflation

- Flat direction
  - ✓ Vacuum degenerate in the scalar potential (SUSY and renormalizable limit)
  - ✓ Slightly lifted by SUSY-breaking effect and non-renormalizable operator

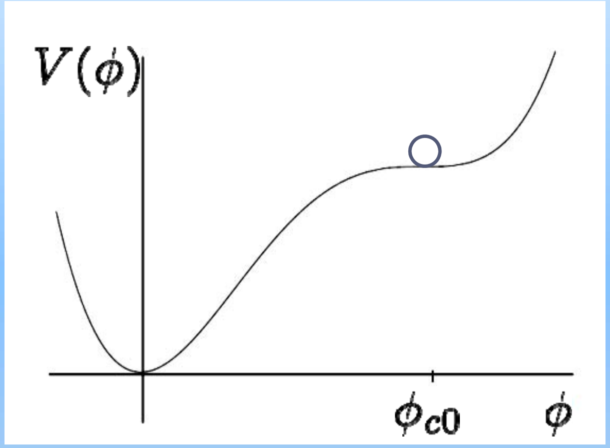
$\longrightarrow$ Flat potential

⇩

Inflaton candidate !

➢MSSM inflation

✓Potential including SUSY breaking effect and non-renormalizable operator



$$V(\phi) = \frac{1}{2}m^2\phi^2 - \frac{A\lambda\phi^6}{24M_G^6} + \frac{\lambda^2\phi^{10}}{32M_G^6}$$

ϕ :parameterization of $\bar{u}\bar{d}\bar{d}$ flat direction

$$(\bar{u}_i^\alpha = \bar{d}_j^\beta = \bar{d}_k^\gamma = \frac{1}{\sqrt{3}}\phi)$$

$m \simeq 1\mathrm{TeV}$ $\lambda \simeq \mathcal{O}(1)$ M_G : reduced Planck mass

✓If $A^2 = 20m^2$, saddle point at $\phi_{c0} = \left(\frac{2AM_G^3}{5\lambda}\right)^{1/4} \simeq 10^{14.5}\mathrm{GeV}$

✓Hubble parameter: $H_{\rm inf} = \frac{2m\phi_{c0}}{\sqrt{5}M_G} \simeq 10^{-15}\phi_{c0}$

$\simeq 1\mathrm{GeV}$

⇨ Low energy inflation

Last inflation !?

➢Fine-tuning

Requirement for inflation

✓Potential parameter: $\dfrac{A^2 - 20m^2}{20m^2} \sim \mathcal{O}(10^{-18})$
(to generate correct density perturbation)

✓Initial condition ϕ_i : $\dfrac{\phi_i - \phi_{c0}}{\phi_{c0}} \sim \mathcal{O}(10^{-2})$

(Slow-roll region $\Delta\phi$: $\dfrac{\Delta\phi}{\phi_{c0}} \sim \mathcal{O}(10^{-10})$)

Can we relax these conditions using the dissipative effect?

Dissipative effect on the MSSM inflation

- Equation of motion in the dissipative regime ('88 Yokoyama & Maeda)

$$\ddot{\phi} + (3H + \Gamma)\dot{\phi} + \frac{\partial V}{\partial \phi} = 0$$

Γ : dissipative coefficient

If $\Gamma \gg 3H$, slow-roll condition will change.

➢ Slow-roll condition

When dissipative coefficient is larger than Hubble parameter, slow-roll conditions change from usual form as follows :

Slow-roll parameters :

$$\epsilon \equiv \frac{M_G^2}{2}\left(\frac{V'}{V}\right)^2, \quad \eta \equiv M_G^2 \frac{V''}{V}, \quad \beta \equiv M_G^2 \frac{\Gamma' V'}{\Gamma V}$$

Slow-roll conditions :

$$\epsilon \ll r \quad \leftarrow \quad \ddot{a} > 0 \ \text{ and } \ \dot{\phi}^2 \ll V(\phi)$$

$$3|\eta - \beta| \ll r^2 \quad \leftarrow \quad \ddot{\phi} \ll \frac{\partial V(\phi)}{\partial \phi}$$

$$r \equiv \frac{\Gamma}{3H}$$

+ Consistency check.
→ Decay product must be the subdominant component of the Universe.

➢Modification to the MSSM inflation

Slow-roll condition for $r < 10^5$

$$3|\eta - \beta| \ll r^2 \quad \Rightarrow \quad \frac{|\phi - \phi_{c0}|}{\phi_{c0}} \ll 10^{-10} r^2$$

⟺ cf.) no dissipation → $|\phi - \phi_{c0}| \ll 10^{-10}\phi_{c0}$

⇨ Slow-roll region is enhanced!

Fine-tuning of the potential parameter and the initial condition is relaxed!

for $r \sim 10^4$

$$\left\{ \begin{array}{l} \dfrac{A^2 - 20m^2}{20m^2} \sim \mathcal{O}(10^{-4}) \\ \text{(condition for slow-roll region to emerge)} \\ \dfrac{\phi_i - \phi_{c0}}{\phi_{c0}} \sim \mathcal{O}(10^{-2}) \end{array} \right.$$

Derivation of dissipative effect

- Interactions of inflaton

$$V_{\rm int} = h_1^2(|\phi|^2|\chi_1|^2 + |\phi|^2|\chi_2|^2 + |\chi_1|^2|\chi_2|^2) + h_1 h_2(\phi\chi_2 y_1^* y_2^* + \text{H.c.})$$
$$+ h_2(|\chi_1|^2|y_1|^2 + |\chi_1|^2|y_2|^2 + |y_1|^2|y_2|^2)$$
$$+ h_1\left(\phi\bar{\psi}_\chi P_L\psi_\chi + \phi^*\bar{\psi}_\chi P_R\psi_\chi\right) + h_2\left(\chi_1\bar{\psi}_y P_L\psi_y + \chi_1^*\bar{\psi}_y P_R\psi_y\right),$$

χ acquires mass from the inflaton

$$m_\chi = h_1|\phi|$$

$\Phi : \bar{u}\bar{d}\bar{d}$: (s)quarks

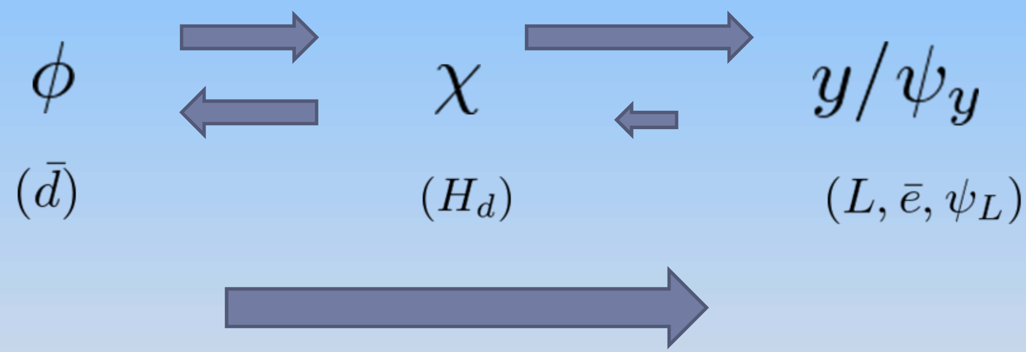
$X : Q, H_u, H_d$: (s)quarks & Higgs(ino)s

$Y : L, \bar{e}$: (s)leptons

➢Energy dissipative process

('84 Morikawa & Sasaki, '01 Berera & Ramos, '06 Moss & Xiong)

The motion of inflaton ϕ ➡ change the mass of other fields χ
➡ particle production of these fields
➡ decay to other fields causes dissipative effect



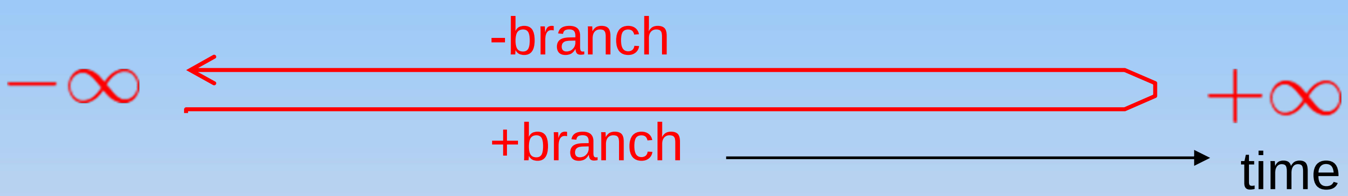
Energy dissipative channels exist !

➢Derivation of dissipative terms

In-in(closed time path) formalism

Generating functional

$$Z[J_i] = \left\langle \text{in} \middle| T_- \left\{ \exp\left[-i \int_{-\infty}^{\infty} dt \int d^3x J_{i-}(x)\phi_i(x) \right] \right\} \right.$$
$$\left. \times \; T_+ \left\{ \exp\left[i \int_{-\infty}^{\infty} dt \int d^3x J_{i+}(x)\phi_i(x) \right] \right\} \middle| \text{in} \right\rangle \equiv e^{iW[J_i]}$$



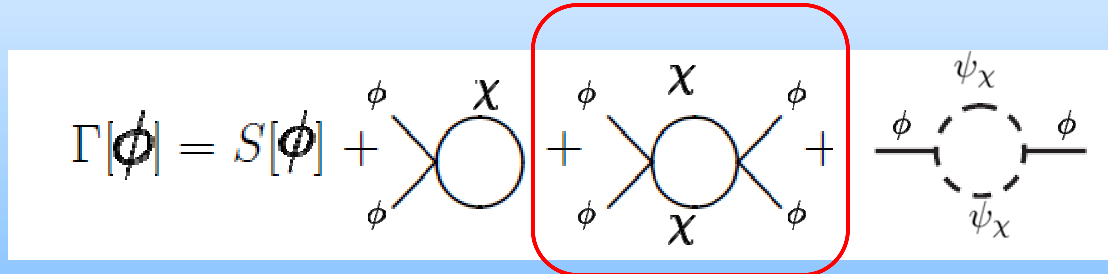
Effective action

$$\Gamma = W - \int dx J\phi$$

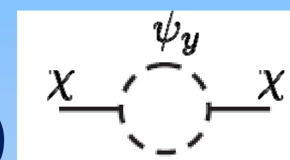
Effective equation of motion

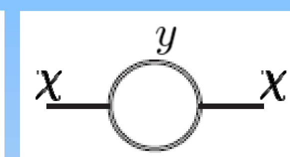
$$\left. \frac{\partial \Gamma}{\partial \phi_\Delta} \right|_{\phi_\Delta = 0} = 0$$

➢Effective action



With dressed propagator of χ
(include the dissipative process)





➢Equation of motion in the slow-roll limit

$$\Box\phi_c(t) + \Gamma\dot{\phi}_c + \left.\frac{\partial(V_+[\phi_c,\phi_\Delta] - V_-[\phi_c,\phi_\Delta])}{\partial\phi^*_\Delta}\right|_{\phi_\Delta=0} = 0,$$

$$\Gamma = \frac{h_1^3 h_2^2}{2048\pi^2}\phi_c$$

➡ $r \sim 10^4$ for $h_1 \sim h_2 \sim \mathcal{O}(10^{-1})$

Conclusion

- ✓MSSM inflation is a candidate for low-energy inflation.
- ✓Dissipative effect can relax the problems of the MSSM inflation.
- ✓Using in-in formalism, we have derived the dissipative term in the equation of motion
- ✓Dissipation coefficient can be larger than Hubble parameter.
  (It depends on the Yukawa coupling and the type of flat direction.)
- ✓Slow-roll region can be dramatically changed. (enhanced!!)
- ✓These effects can be the key to the realization of the MSSM inflation.