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“Curvaton induced modulated reheating”

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Curvaton induced modulated reheating

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Based on: corrected* **Phys. Rev. D 85, 123528 (2012)**

*Thanks to S.Yokoyama, T.Suyama and D.Wands

Are you ready for this?

First year Planck observations:
Full sky maps and cosmological implications.

Authors...

Abstract We present full sky microwave from the Planck first year sky survey. …. The age of the Universe…….Nonlinearity of local type f_NL^local(k_0=0.002 Mpc^-1)=15 +/- 9 (95% CL) is detected. …. index n_s = 0.97 +/- 0.02... The B-mode polarization is also detected. The corresponding tensor-to-scalar ratio is estimated as rT(k_0=0.002 Mpc^-1)=0.10 +/- 0.03 (95% CL).

§ Introduction

- Inflation

  is an elegant solution to

  horizon, flatness, monopole problem

  and

  provides the seed of density fluctuation of

  adiabatic,

  almost scale invariant, and Gaussian

  as well as tensor modes.

Non-Gaussianity in perturbation generation

- Inflaton ϕ [Hawking, Guth and Pi,… 1982]

  $f_{NL} = \mathcal{O}(\epsilon, \eta)$ [Maldacena 2003]

- Curvaton σ [Lyth and Wands, Moroi and Takahashi, Enqvist and Sloth 2001~2]

  $f_{NL} = \mathcal{O}(1/R)$ [Lyth et al 2003,…]

- Modulated reheating by a light scalar σ [Kofman 2003, Dvali et al 2004]

$$\delta\Gamma_{\phi}[\sigma] \neq 0 \quad \Longrightarrow \quad \delta T/T \neq 0$$

$f_{NL} = f_{NL}(\Gamma, \partial\Gamma, \ldots)$ [Zaldarriaga 2004,…]

System in perturbation generation

- Inflaton ϕ [Hawking, Guth and Pi,… 1982]

  Inflaton ϕ

- Curvaton σ [Lyth and Wands, Moroi and Takahashi, Enqvist and Sloth 2001~2]

  Inflaton ϕ + Curvaton σ

- Modulated reheating by a light scalar σ [Kofman 2003, Dvali et al 2004]

  Inflaton ϕ + Light scalar σ

System in perturbation generation

- Inflaton ϕ [Hawking, Guth and Pi,… 1982]

  Inflaton ϕ

- Curvaton σ [Lyth and Wands, Moroi and Takahashi, Enqvist and Sloth 2001~2]

  "massive" + "decaying" + "non ϕ interacting"

  Inflaton ϕ + Curvaton σ

- Modulated reheating by a light scalar σ [Kofman 2003, Dvali et al 2004]

  What's difference?

  Inflaton ϕ + Light scalar σ

  "massless" + "ϕ interacting"

§ ϕ-σ interaction

- Inflaton ϕ - Curvaton/light scalar σ interactions may exist.

- If ϕ and σ are singlet, there might be

$$\mathcal{L}_{\rm int} = \phi\, \sigma\, \mathcal{O}_{\rm SM} + \text{tiny}\ \phi^2 \sigma^2 + \ldots, .$$

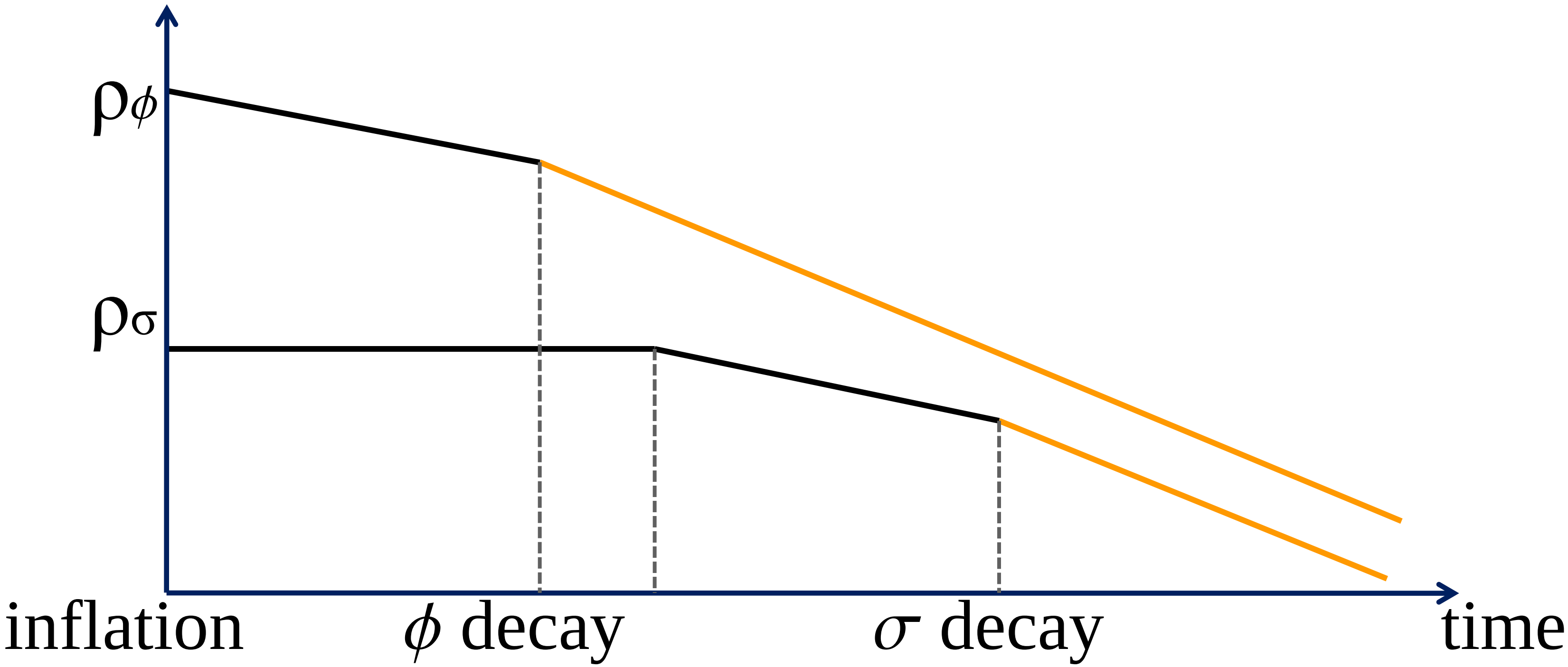
- ex.)

$$\mathcal{L}_{\rm int} = \phi\, \sigma\, |\Phi|^2 \quad \text{then} \quad \Gamma_\phi \propto \sigma^2$$

- Modulated reheating by curvaton [Suyama et al 2010]

§ General analysis

- Inflaton ϕ and another scalar σ
- Thermal history after inflation



§ General analysis

- Inflaton ϕ and another scalar σ
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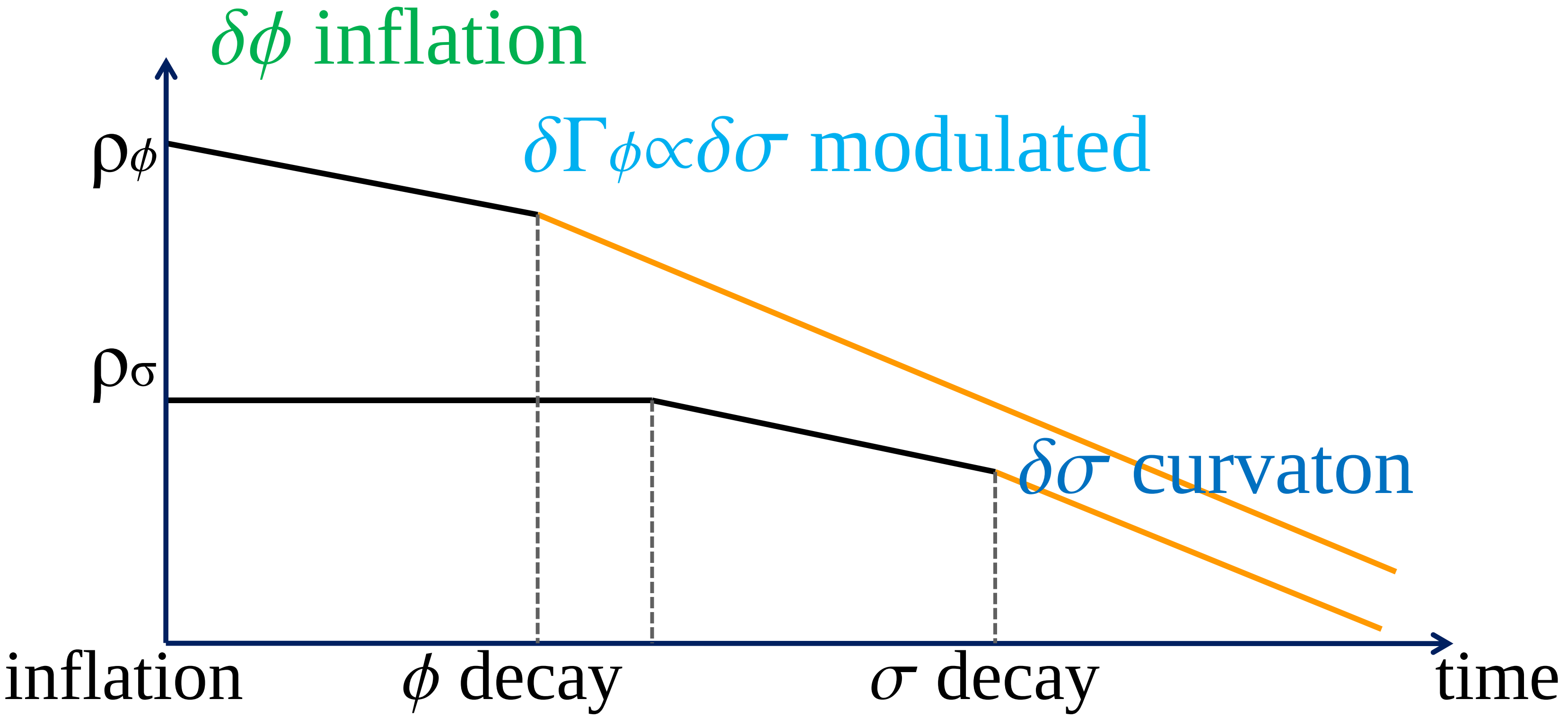


§ § Formula of perturbation

- After σ decay:

  inflaton-modulated mixed [Zaldarriaga 2004, Ichikawa et al 2008] + curvaton

- On uniform σ density hypersurface

$$\zeta = (1-R)\zeta_r + R\zeta_\sigma = \zeta_r + \frac{R}{3}S_\sigma$$

$$R \equiv \left.\frac{3\rho_\sigma}{4\rho_r + 3\rho_\sigma}\right|_{H=\Gamma_\sigma} \qquad S_\sigma \equiv 3(\zeta_\sigma - \zeta_r)$$

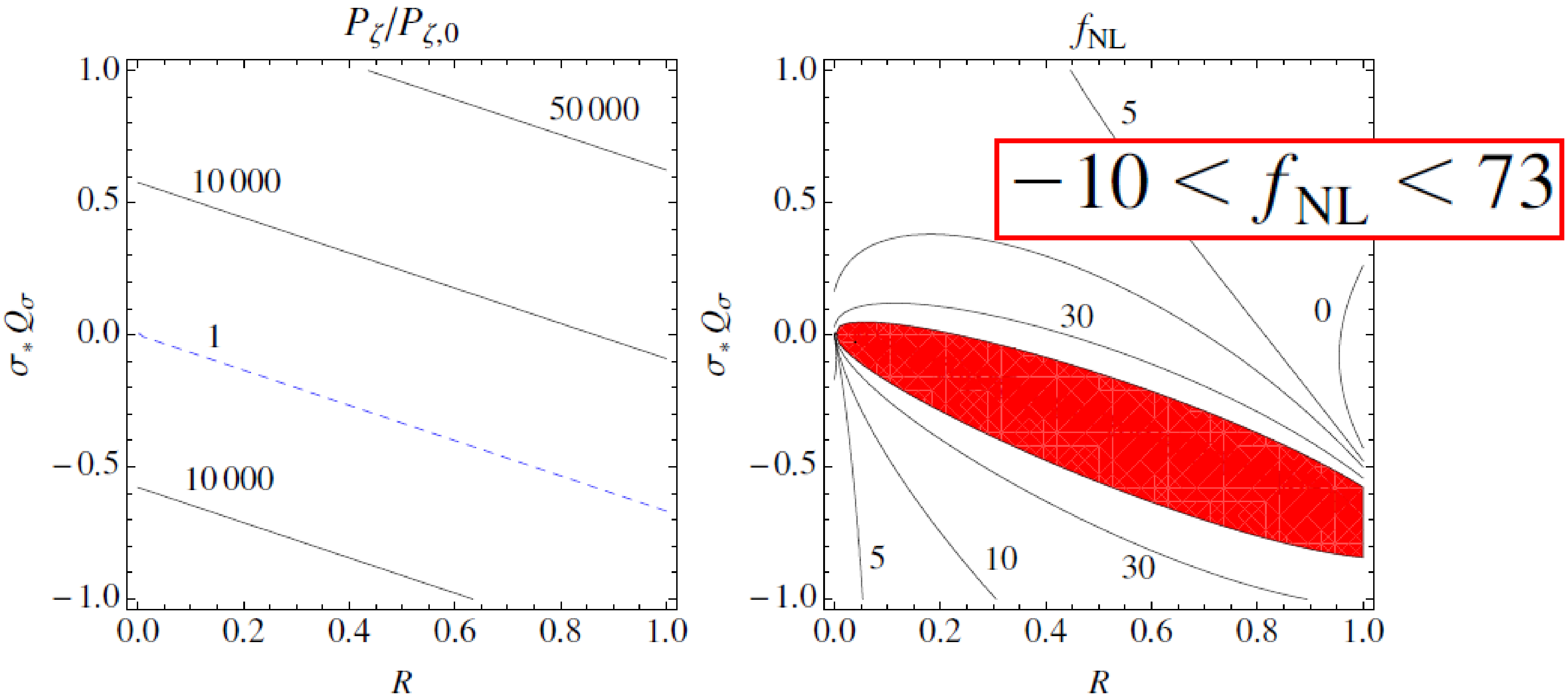
- Power spectrum $\qquad Q$ is a function of $\Gamma_\phi(\sigma)/H_c$

$$\mathcal{P}_\zeta = \frac{1}{2M_P^2\epsilon_*}\mathcal{P}_{\delta\phi_*} + \left(Q_\sigma + \frac{2R}{3\sigma_*}\right)^2 \mathcal{P}_{\delta\sigma_*}$$

§ § Resultant perturbation

- Important parameters: σ_*, R, $\{\sigma_* Q_\sigma, \sigma_*^2 Q_{\sigma\sigma}, \ldots\}$

ϕ-σ ratio Modulated

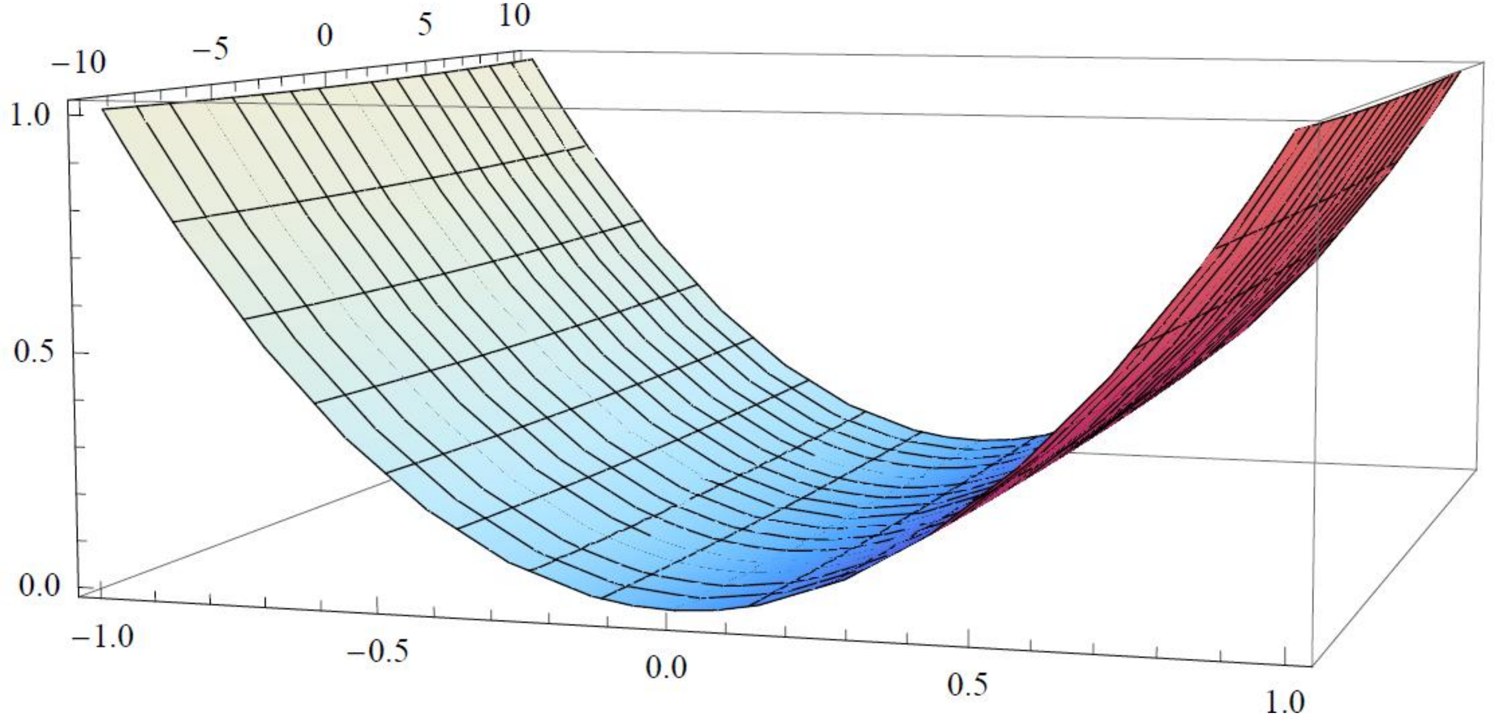


- Small σ_* case : mainly σ originated

§ Simplest case

- Potential

$$V[\phi, \sigma] = \frac{1}{2}m_\phi^2\phi^2 + \frac{1}{2}m_\sigma^2\sigma^2$$



§ § Power spectrum

- Power spectrum

$$\mathcal{P}_\zeta \simeq \frac{1}{6(2\pi)^2}\frac{m_\phi^2}{M_P^2}(2N_{\rm inf}+1)^2 + \left\{Q_\sigma \sigma_* + \frac{2R}{3}\right\}^2 \frac{m_\phi^2}{3(2\pi\sigma_*)^2}(2N_{\rm inf}+1)$$

§ § Power spectrum

- Power spectrui

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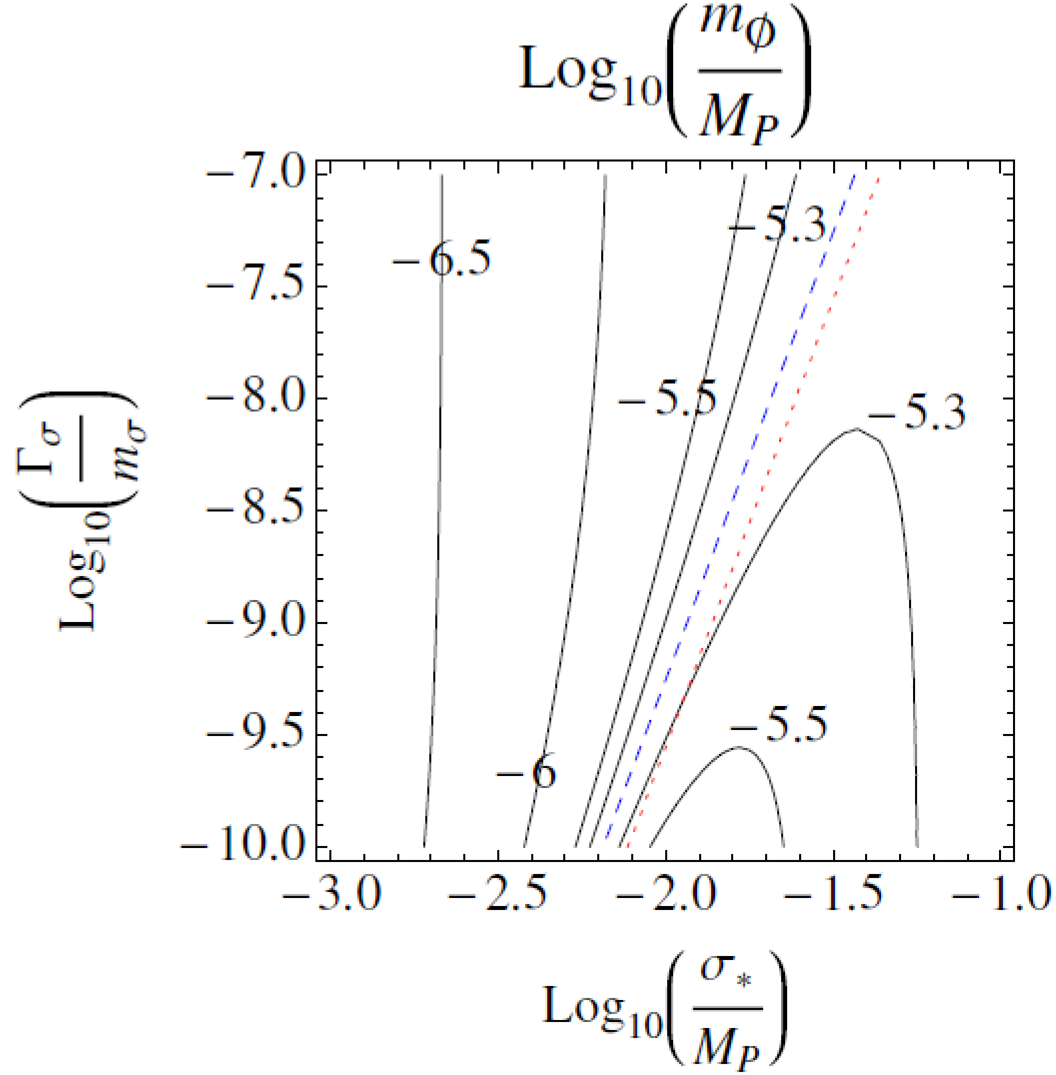


§ § Tensor and nonlinearity

- Model I
- Interaction

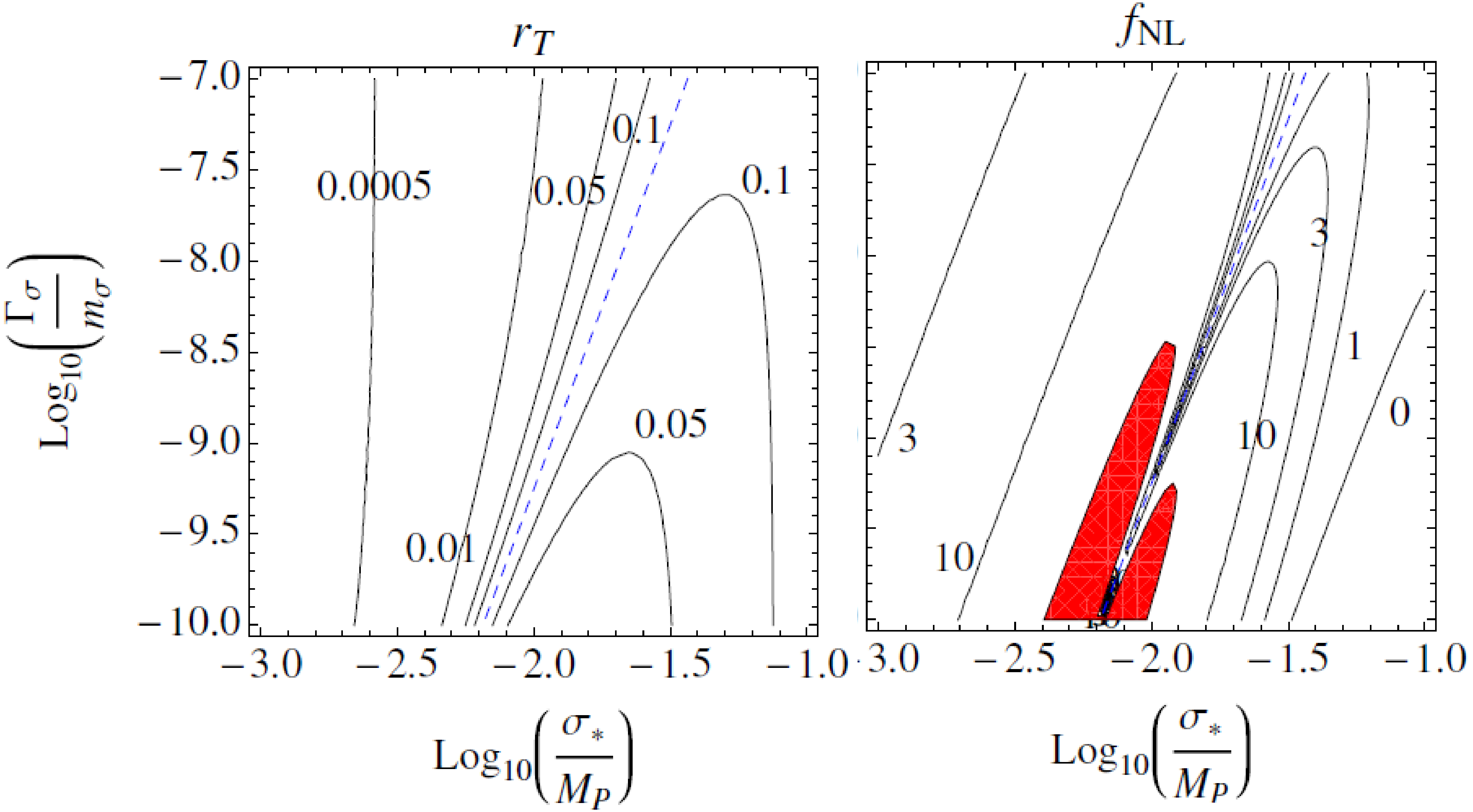
$$\mathcal{L}_{\rm int} = \lambda|\Phi|^2\phi\sigma$$

- Decay rate

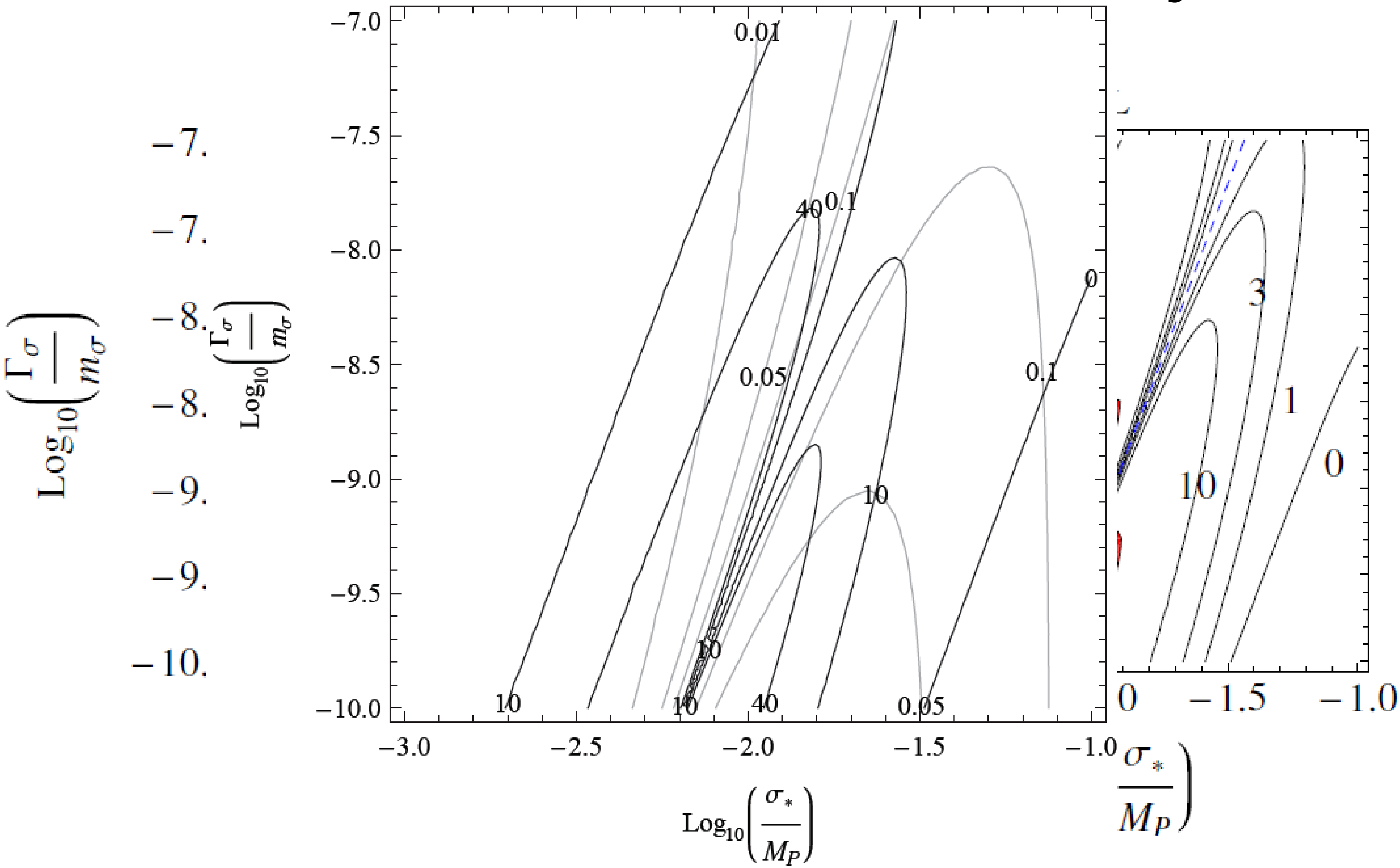
$$\Gamma_\phi^{\rm CD}(\sigma) = \frac{1}{8\pi m_\phi}\lambda^2\sigma^2$$

$$(Q_\sigma\sigma_*, Q_{\sigma\sigma}\sigma_*^2, Q_{\sigma\sigma\sigma}\sigma_*^3) = \left(-\frac{1}{3}, \quad \frac{1}{3}, \quad -\frac{2}{3}\right)$$

§ § Tensor and nonlinearity



§ § Tensor and nonlinearity



§ Summary

- ***"Inflaton-modulated-curvaton mixed"***

- Interaction between ϕ and σ is a subject to be studied.

- An interesting possibility: simultaneous large f_{NL} and r_T