Constraining a curvaton with VEV

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§ 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.

Gaussian fluctuation?

- Inflaton in a single field inflation

  ≈ very weakly interacting (slow roll)

  ≈ nearly free field

  ≈ Gaussian quantum fluctuation

nonlinear parameters are of order of slow roll parameters; $f_{NL} = O(\varepsilon,\eta)$

Maldacena 2003

A large non-Gaussianity

- Curvaton is a promising mechanism

Lyth et al 2003

- What is a “curvaton”?

Lyth and Wands, Moroi and Takahashi, Enqvist and Sloth 2001~2

· Not inflaton!

· Scalar field with a flat potential, which condensates during inflation

- Field fluctuation is converted into density fluctuation

Curvaton models

- Different forms of Potential
- Quadratic [many many...]

$$V = \frac{1}{2} m_\sigma^2 \sigma^2$$

- +Quartic [Enqvist et al, Huang,...]
- Cosin type [Kawasaki et al, Huang,...]
- Double well [Choi and Seto]

$$V(\sigma) = \frac{\lambda}{4} \left(\sigma^2 - v^2\right)^2$$

§ A Model

- Double well potential with a large VEV [DW problem] and a small self-coupling [Flatness]

$$\mathcal{L} = -\frac{1}{2}(\partial\sigma)^2 - V(\sigma)$$

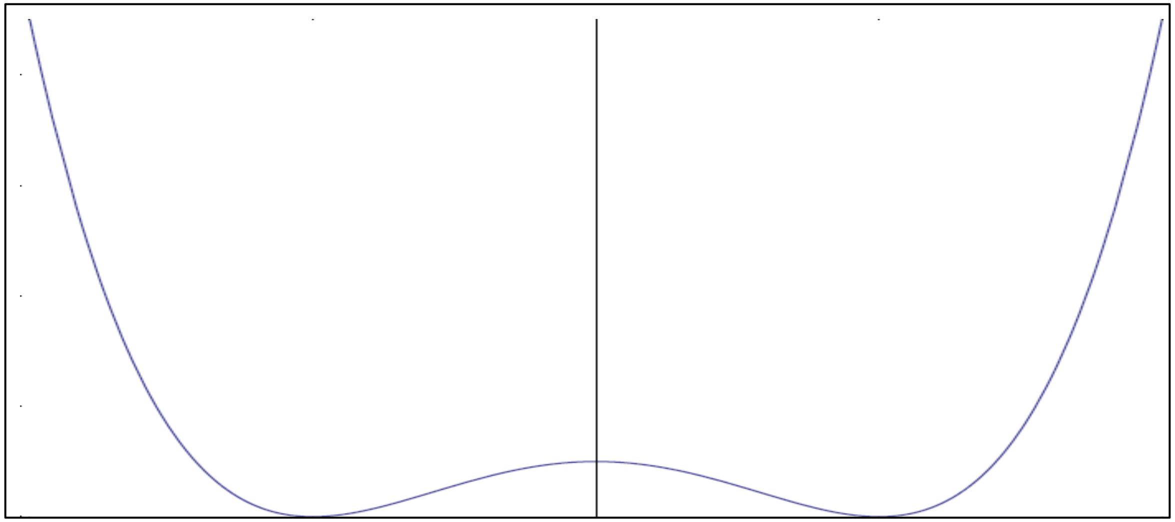
$$V(\sigma) = \frac{\lambda}{4}\left(\sigma^2 - v^2\right)^2$$

- Decay rate [saxion-like]

$$\Gamma_\sigma = C\frac{m_\sigma^3}{v^2} = C(2\lambda)^{3/2}v$$

§ § Cosmological evolution

- Rough history



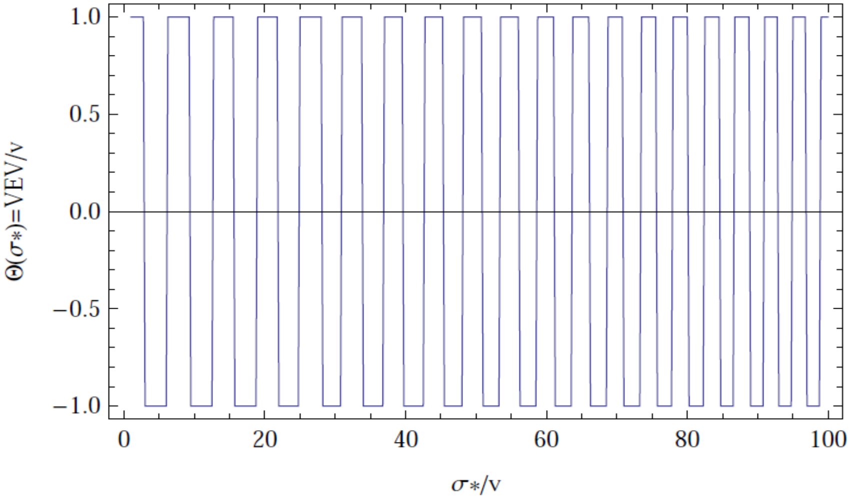
- Quartic to quadratic transition

At the time when the energy density becomes comparable with the height of potential hill

$$\rho_\sigma\big|_v = \frac{\lambda}{4}(\sigma_v^2 - v^2)^2$$

§ § Cosmological evolution 2

- +v or –v?



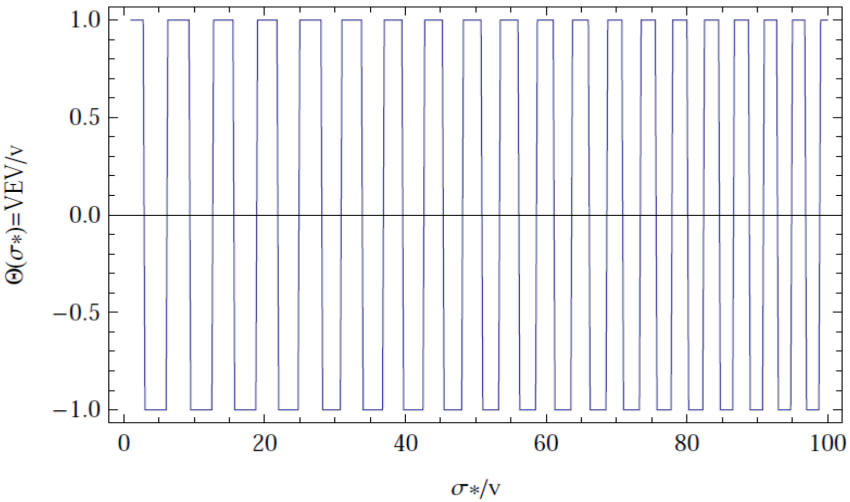
- Analytic solutions from the scaling law

$$\sigma(t) \simeq v\Theta(\sigma_{\rm os}) + \frac{\sigma_{2\rm os}}{(m_\sigma t)^{3/4}} \sin m_\sigma t$$

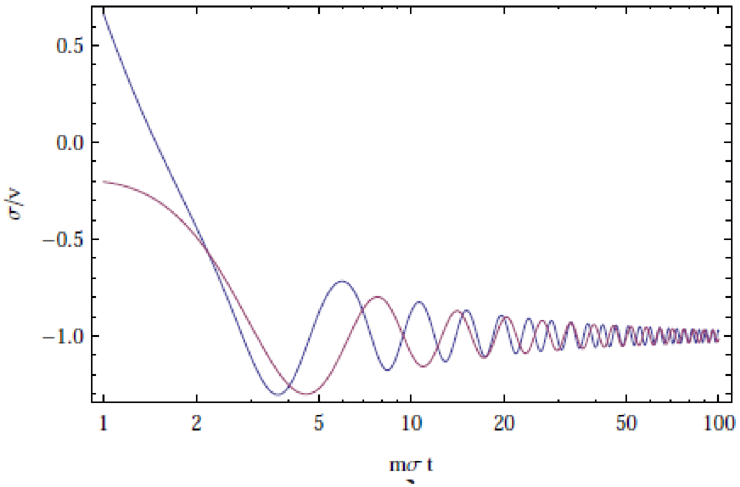
$$\sigma_{2\rm os} \simeq \begin{cases} (\sigma_v - v)\left(\frac{\rho_\sigma|_{\rm os}}{\rho_\sigma|_v}\right)^{3/8}\left(\frac{m_\sigma}{2\sqrt{3\lambda\sigma_{\rm os}^2}}\right)^{3/4}, \\ (\sigma_v - v)\left(\frac{\rho_\sigma|_{\rm os}}{\rho_\sigma|_v}\right)^{3/8}\left(\frac{H_R}{2\sqrt{3\lambda\sigma_{\rm os}^2}}\right)^{1/4}\left(\frac{m_\sigma}{2\sqrt{3\lambda\sigma_{\rm os}^2}}\right)^{3/4} \end{cases}$$

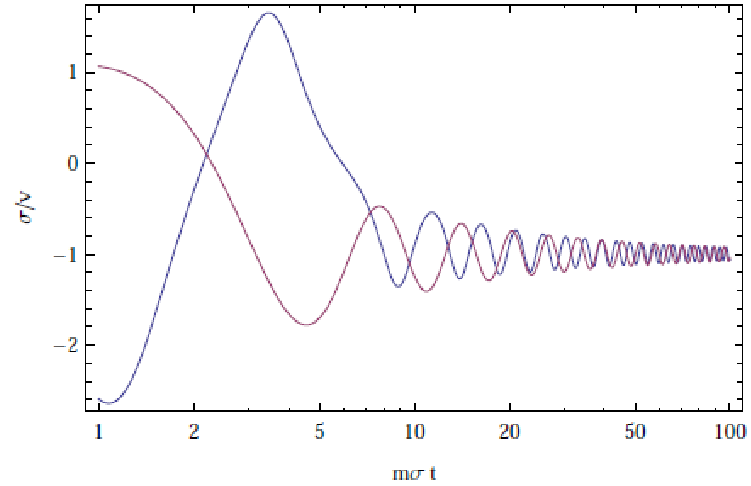
§ § Cosmological evolution 2

- +v or –v?



- Analytic solutions fit well!

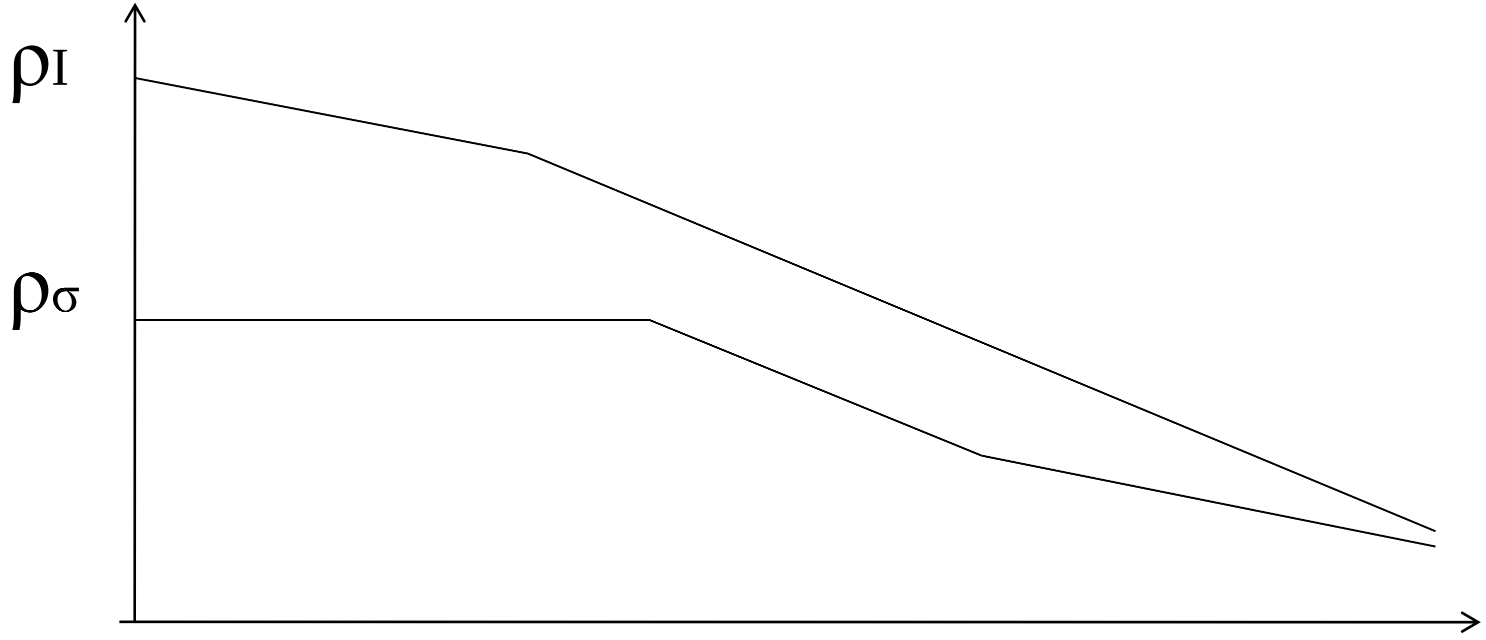




§§ Cosmological evolution 3.1

- Reheating temperature T_R dependence

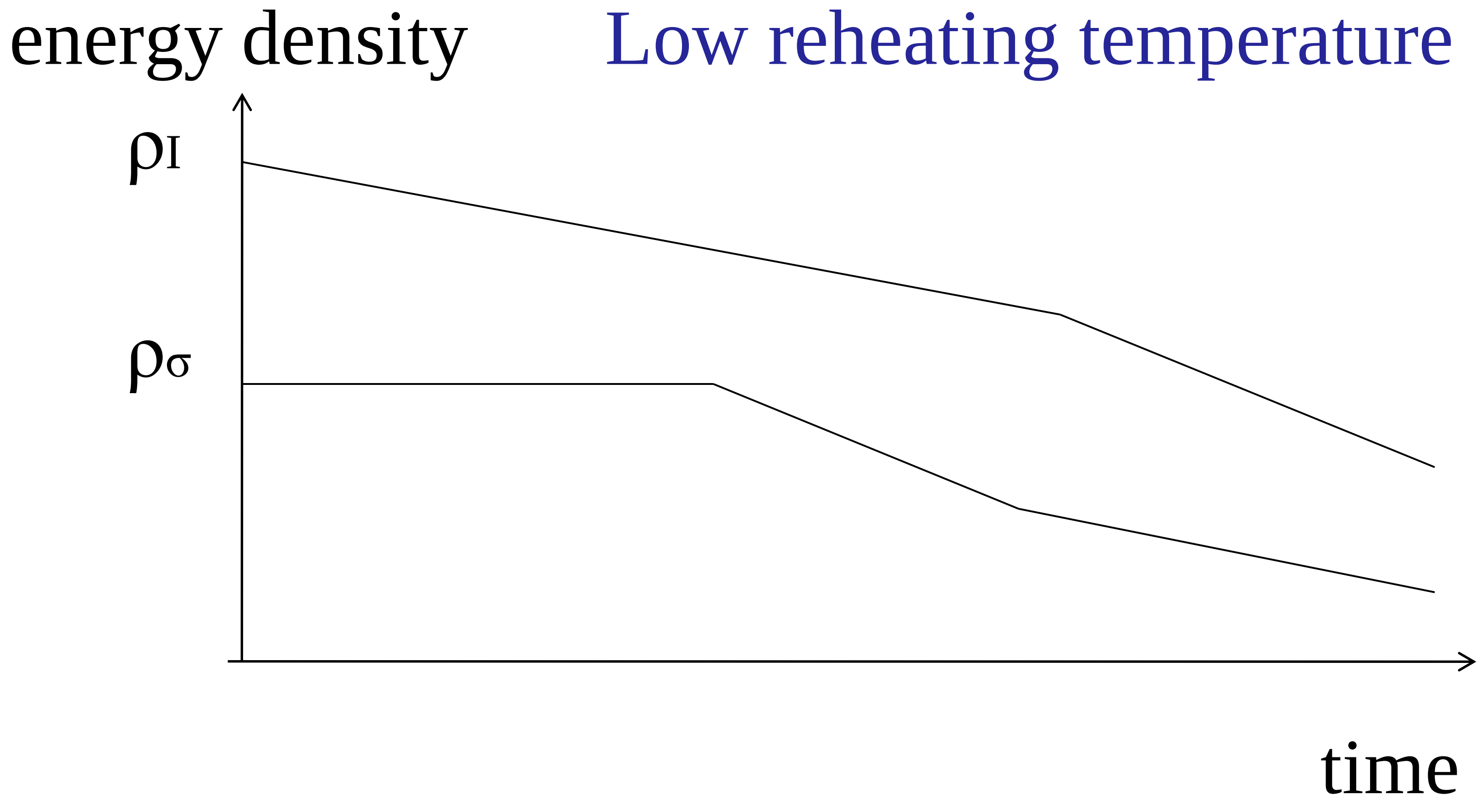
energy density High reheating temperature



time

§ § Cosmological evolution 3.2

- Reheating temperature T_R dependence



§ Density perturbation

- We estimate power spectrum and non-Gaussianity in terms of nonlinear parameters f_{NL} and g_{NL}
- We impose the constraints from the null detection of tensor mode fluctuation

§ § Formulation 1

- We employ δN formalism for perturbation
  Lyth et al, Sasaki et al

$$\zeta_\sigma = \delta N + \frac{1}{3}\int_{\rho_0(t)}^{\rho(t,\mathbf{x})} \frac{d\tilde{\rho}}{\tilde{\rho}+\tilde{p}}$$

  on the uniform curvaton density surface.

- Expand this with the late time energy density expression $\rho_\sigma(t,x) \simeq \frac{m_\sigma^2 \sigma_{2\mathrm{os}}^2(t,x)}{2(mt)^{3/2}}$

§ § Formulation 2

- The power spectrum

$$\mathcal{P}_\zeta = (1-R)^2\mathcal{P}_{\zeta_r} + R^2\mathcal{P}_{\zeta_\sigma}$$

$$\mathcal{P}_{\zeta_r} = \left(\frac{H_*^2}{2\pi|\dot{\phi}|}\right)^2 = \frac{H_*^2}{8\pi^2\epsilon M_P^2},$$

$$\mathcal{P}_{\zeta_\sigma} = \frac{H_*^2}{4\pi^2}\left(\frac{2\sigma'_{2\mathrm{os}}}{3\sigma_{2\mathrm{os}}}\right)^2$$

$$R \equiv \frac{3\rho_\sigma}{4\rho_r + 3\rho_\sigma}$$

$$\tilde{r} \equiv \frac{R^2\mathcal{P}_{\zeta_\sigma}}{(1-R)^2\mathcal{P}_{\zeta_r}}$$

- Non-linear parameters

$$f_{NL} = \frac{5}{6}\frac{\tilde{r}^2}{(1+\tilde{r})^2}\left[\frac{3+A_2}{R} - 2 - R\right],$$

$$g_{NL} = \frac{25}{54}\frac{\tilde{r}^3}{(1+\tilde{r})^3}\left[\frac{9+9A_2+A_3}{R^2} - \frac{18+6A_2}{R} - 4 - 3A_2 + 10R + 3R^2\right].$$

§ § Formulation 3

- The power spectrum

$$\mathcal{P}_\zeta = (1-R)^2\mathcal{P}_{\zeta_r} + R^2\mathcal{P}_{\zeta_\sigma}$$

$$\mathcal{P}_{\zeta_r} = \left(\frac{H_*^2}{2\pi|\dot{\phi}|}\right)^2 = \frac{H_*^2}{8\pi^2\epsilon M_P^2},$$

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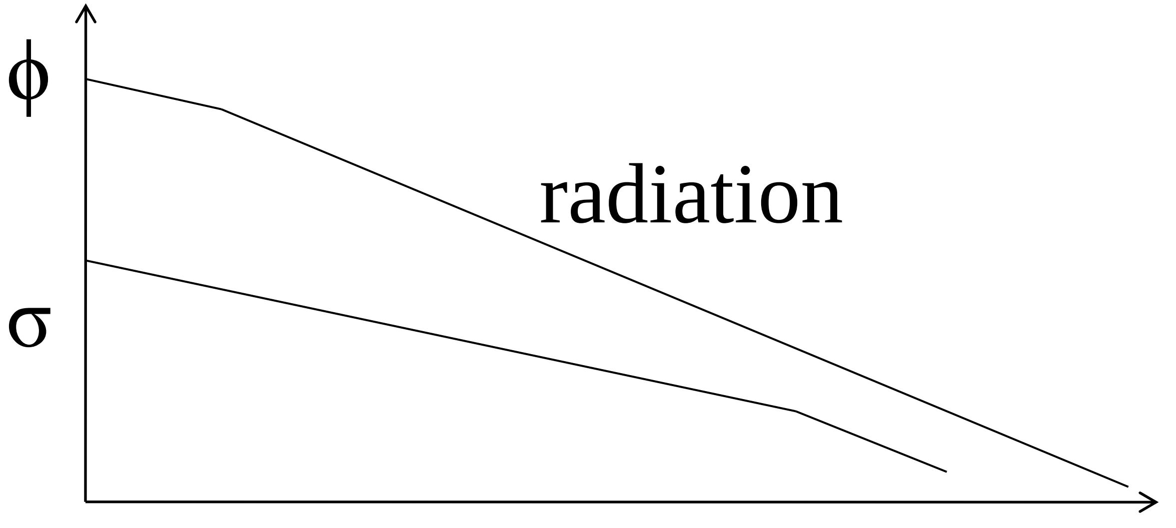
Intuitive understanding of 1/R

- If mainly subdominat curvaton generate $\delta T/T$



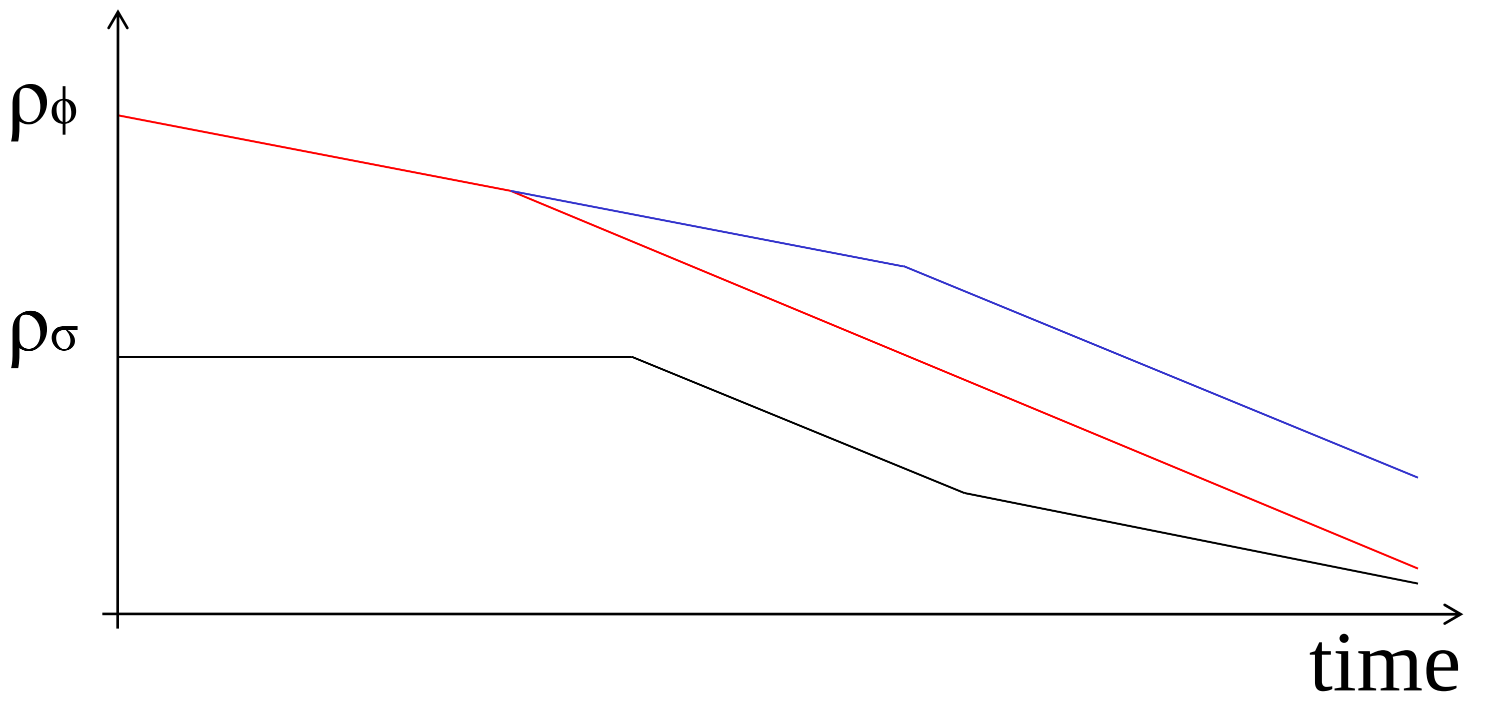
- ζ_σ is diluted, $\zeta_\sigma \rightarrow \zeta = R\,\zeta_\sigma$
- Second/(first)$^2 \approx O(R/R^2) = O(1/R)$

"subdominat curvaton predict a large f_{NL}"

Wands et al, Langlois et al, Enqvist et al,...

§ § Reheating temperature for a large initial amplitude

- Reheating temperature T_R (background evolution) affects parameters somewhat



§ § Large initial expectation 1/5

- Curvature perturbation ζ

$$\zeta = (1-R)\zeta_r + \frac{R}{2}\left(\frac{\delta\sigma_*}{\sigma_*}\right) + \frac{1}{8}\left(\frac{1}{R} - 2 - R\right) R^2 \left(\frac{\delta\sigma_*}{\sigma_*}\right)^2 + \frac{1}{48}\left(-\frac{1}{R^2} - \frac{6}{R} + 2 + 10R + 3R^2\right) R^3 \left(\frac{\delta\sigma_*}{\sigma_*}\right)^3, \qquad \text{for high } T_R,$$

$$\zeta = (1-R)\zeta_r + \frac{R}{3}\left(\frac{\delta\sigma_*}{\sigma_*}\right) + \frac{1}{18}\left(-2 - R\right) R^2 \left(\frac{\delta\sigma_*}{\sigma_*}\right)^2 + \frac{1}{162}\left(5 + 10R + 3R^2\right) R^3 \left(\frac{\delta\sigma_*}{\sigma_*}\right)^3, \qquad \text{for low } T_R,$$

§ § Large initial expectation 2/5

- Curvature perturbation ζ

$$\zeta = (1-R)\zeta_r + \frac{R}{2}\left(\frac{\delta\sigma_*}{\sigma_*}\right) + \frac{1}{8}\left(\frac{1}{R} - 2 - R\right)R^2\left(\frac{\delta\sigma_*}{\sigma_*}\right)^2 + \frac{1}{48}\left(-\frac{1}{R^2} - \frac{6}{R} + 2 + 10R + 3R^2\right)R^3\left(\frac{\delta\sigma_*}{\sigma_*}\right)^3, \qquad \text{for high } T_R,$$

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Absence of inverse power of R

§ § Large initial expectation 3/5

- Resultant nonlinear parameters

$$f_{\rm NL} = \left(\frac{\tilde{r}}{1+\tilde{r}}\right)^2 \frac{5}{6}\left(\frac{1}{R} - 2 - R\right) > -2$$

$$g_{\rm NL} = \left(\frac{\tilde{r}}{1+\tilde{r}}\right)^3 \frac{25}{54}\left(-\frac{1}{R^2} - \frac{6}{R} + 2 + 10R + 3R^2\right), \qquad \text{for high } T_R,$$

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§ § Large initial expectation 3/5

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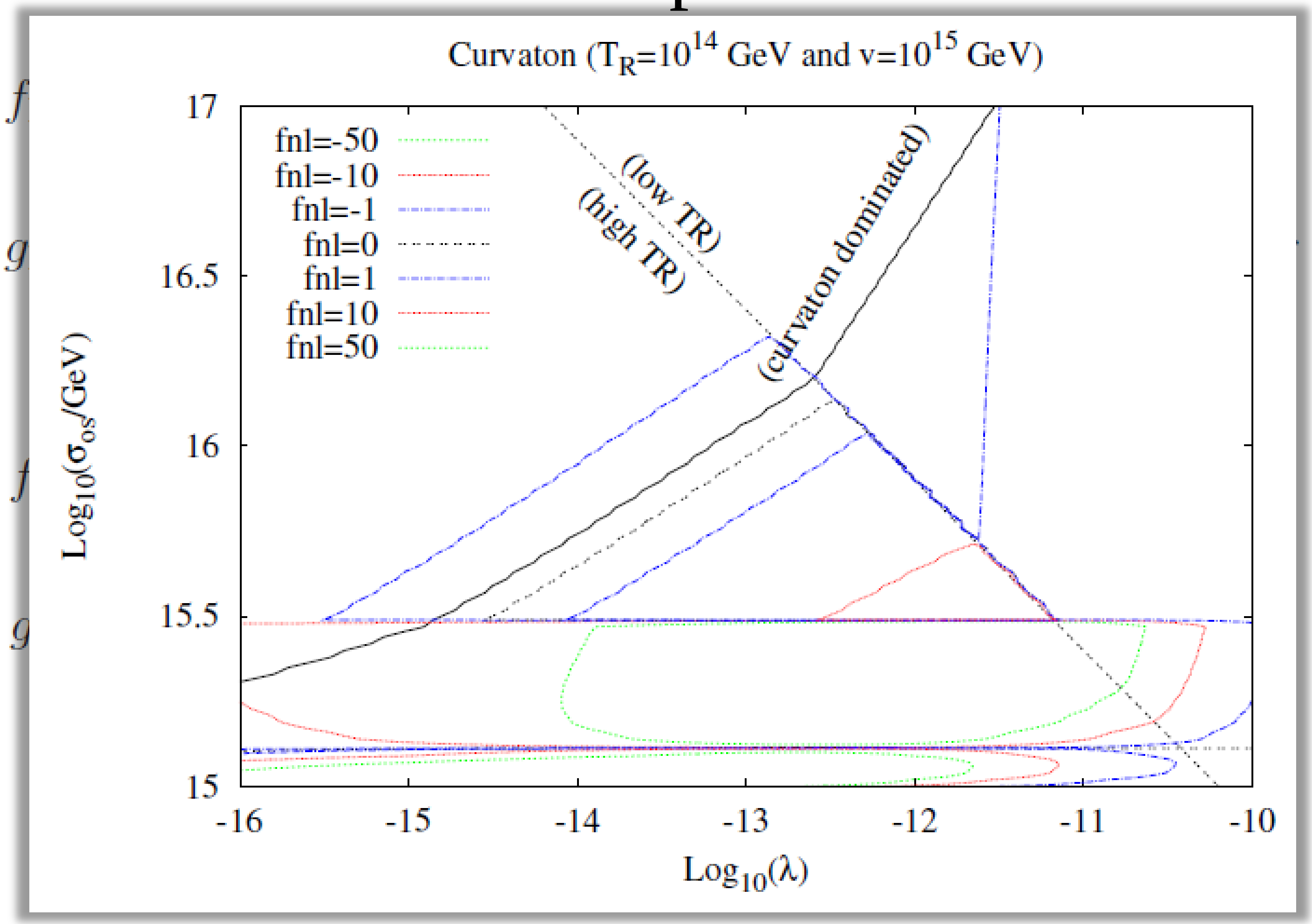
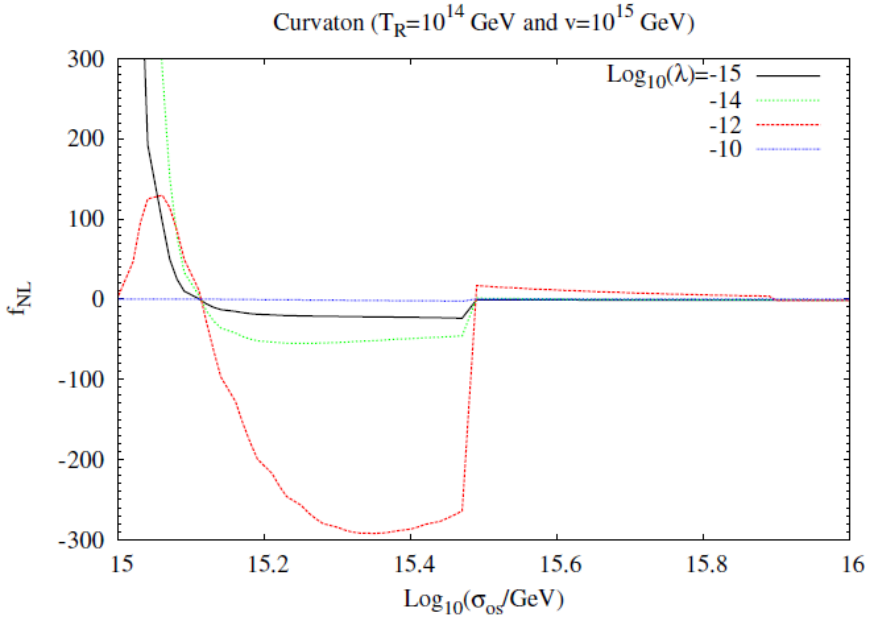


high T_R,

§ § Large initial expectation 4/5

- Another feature of nonlinear parameters



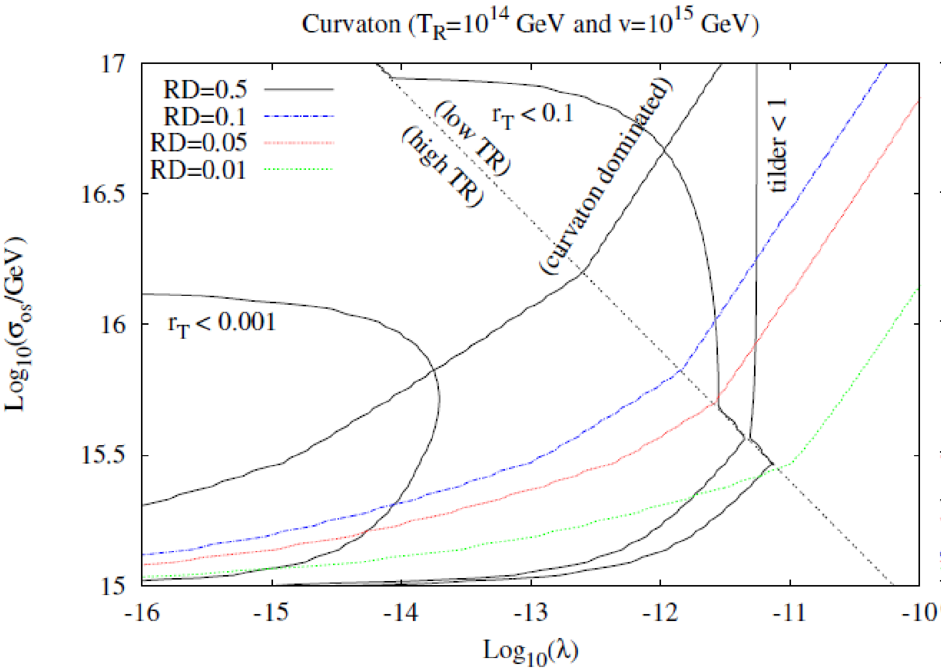
Observation

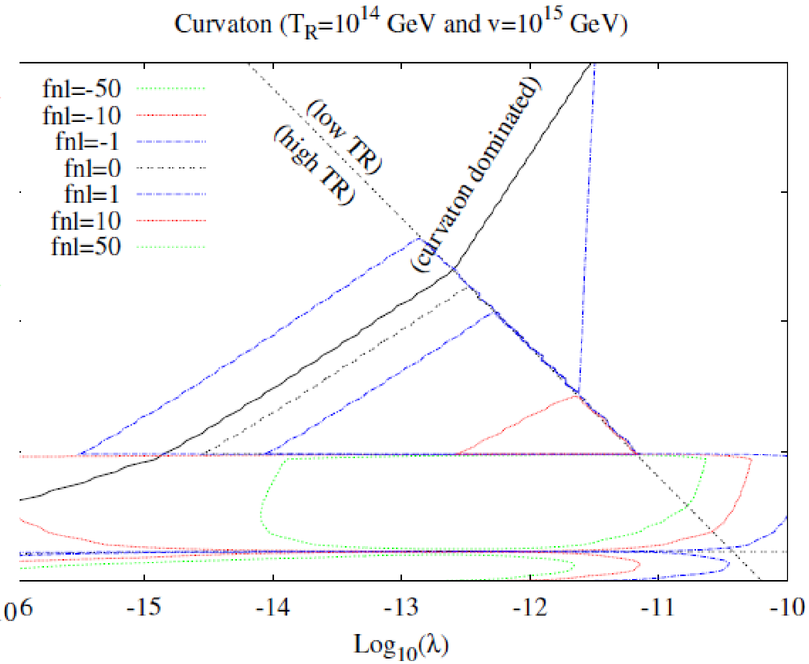
$$-10 < f_{\rm NL} < 74$$

- A negative f_{NL} is possible, unlike quadratic curvaton.

§ § Large initial expectation 5/5

- Tensor (gravitational wave) modes





§ Summary

We have studied curvaton model which has a double well potential

- **For a low reheating temperature, f_{NL} can not be large because of accidental cancellations**

The statement "a subdominant curvaton predict a large f_{NL}" is not ALWAYS ture

- **The present bounds on f_{NL} and r_T already constrain parameters and future's will do further.**