Title: Density Perturbations from Curvatons Revisited

Date: Apr 24, 2012 11:00 AM

URL: http://pirsa.org/12040058

Abstract: The curvaton scenario provides a simple explanation for the generation of the cosmological perturbations, however most works have focused on cases with rather trivial curvaton energy potentials, e.g. quadratic ones. In this talk I will present the rich phenomenology of curvatons by showing that non-quadratic curvatons exhibit new behaviors, leading to interesting signals in the resulting density perturbations. A string theory realization of the curvaton scenario will also be discussed, where D-branes located in a warped throat region of the internal space play the role of curvatons.

Density Perturbations from Curvatons Revisited

Takeshi Kobayashi (CITA)

based on: arXiv:0905.2835 w/ S. Mukohyama
arXiv:1107.6011 w/ M. Kawasaki, F. Takahashi
arXiv:1203.3011 w/ T. Takahashi

PI, April 24, 2012

How was Structure Seeded?

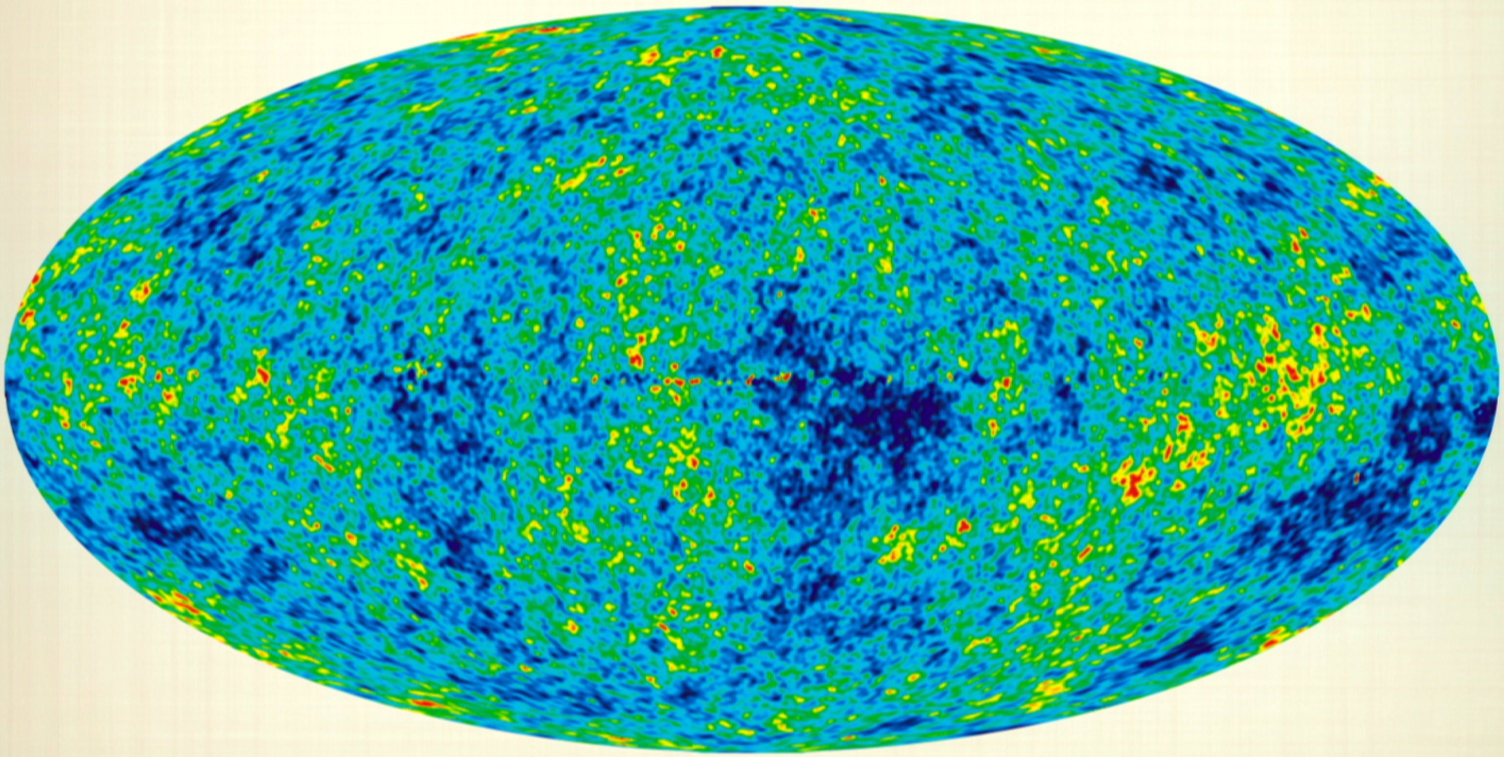


image: NASA/WMAP Science Team

The Curvaton Paradigm

Enqvist, Sloth ’01   Lyth, Wands ’01   Moroi, Takahashi ’01

- a mechanism for generating density perterbations from a “curvaton” field
- seeds : curvaton field fluctuations sourced during inflation (or Horava-Lifshitz gravity, Galilean mechanism, etc.)

The Curvaton Paradigm

Enqvist, Sloth '01 Lyth, Wands '01 Moroi, Takahashi '01

- a mechanism for generating density perterbations from a "curvaton" field
- seeds : curvaton field fluctuations sourced during inflation (or Horava-Lifshitz gravity, Galilean mechanism, etc.)

Curvatons in the Literature

most studies have been limited to rather trivial curvaton energy potentials, e.g., quadratic ones

however...

- microscopic realizations can give complicated energy potentials
- observational constraints on the spectral index requires a tachyonic potential, or rather large $|\dot{H}/H^2|$

$$n_s - 1 = \frac{2}{3}\frac{V''}{H^2} + 2\frac{\dot{H}}{H^2} = -0.032 \pm 0.012 \quad \text{(WMAP7, 68\%CL)}$$

Curvatons in the Literature

most studies have been limited to rather trivial curvaton energy potentials, e.g., quadratic ones

however...

- microscopic realizations can give complicated energy potentials
- observational constraints on the spectral index requires a tachyonic potential, or rather large $|\dot{H}/H^2|$

$$n_s - 1 = \frac{2}{3}\frac{V''}{H^2} + 2\frac{\dot{H}}{H^2} = -0.032 \pm 0.012 \quad \text{(WMAP7, 68\%CL)}$$

Curvatons in the Literature

most studies have been limited to rather trivial curvaton energy potentials, e.g., quadratic ones

however...

- microscopic realizations can give complicated energy potentials

- observational constraints on the spectral index requires a tachyonic potential, or rather large $|\dot{H}/H^2|$

$$n_s - 1 = \frac{2}{3}\frac{V''}{H^2} + 2\frac{\dot{H}}{H^2} = -0.032 \pm 0.012 \quad \text{(WMAP7, 68\%CL)}$$

Curvatons in the Literature

most studies have been limited to rather trivial curvaton energy potentials, e.g., quadratic ones

We need to go beyond simple quadratic curvatons!

- observational constraints on the spectral index requires a tachyonic potential, or rather large $|\dot{H}/H^2|$

$$n_s - 1 = \frac{2}{3}\frac{V''}{H^2} + 2\frac{\dot{H}}{H^2} = -0.032 \pm 0.012 \quad \text{(WMAP7, 68\%CL)}$$

Curvatons with Generic Potentials

- non-quadratic curvatons behave quite differently from quadratic ones
- interesting features in cosmological observables, especially in non-Gaussianity
- Our analyses are analytic!

Curvatons with Generic Potentials

- non-quadratic curvatons behave quite differently from quadratic ones
- interesting features in cosmological observables, especially in non-Gaussianity
- Our analyses are analytic!

Outline

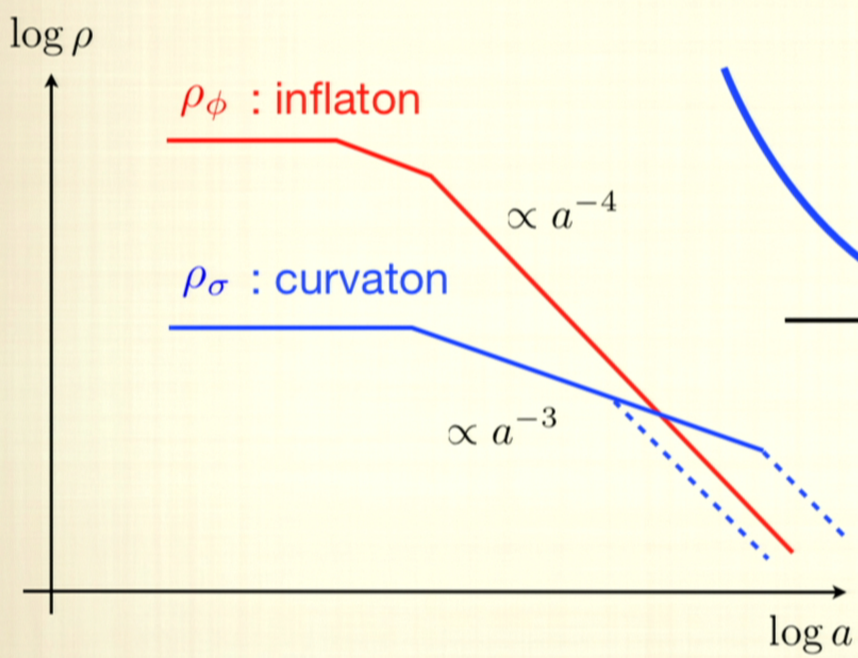
- curvatons with generic energy potentials
- enhanced density perturbations from flat potentials
- running non-Gaussianity from steep potentials
- a stringy realization : curvatons in warped throats

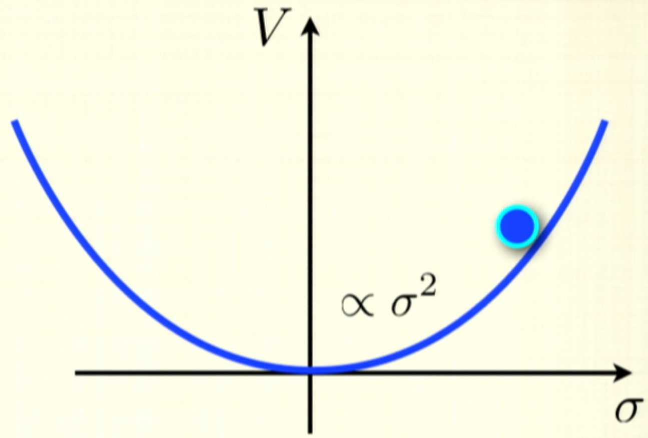
Curvatons with Generic Potentials

Kawasaki, TK, Takahashi '11
TK, Takahashi '12

The Quadratic Curvaton Scenario

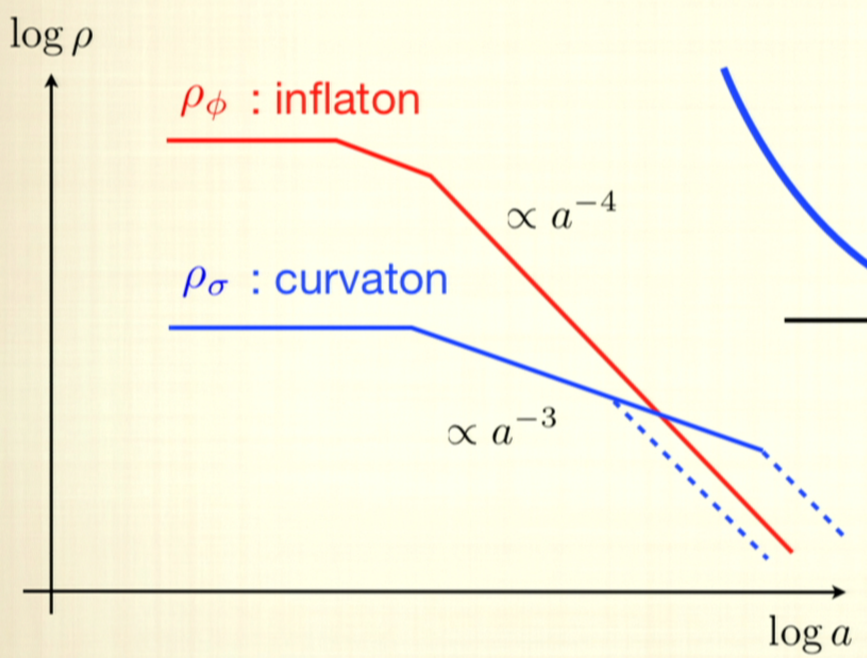
: a light field with negligible energy density during inflation

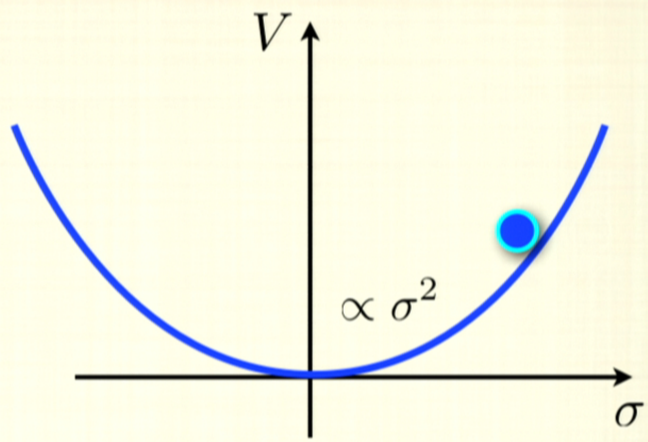




The Quadratic Curvaton Scenario

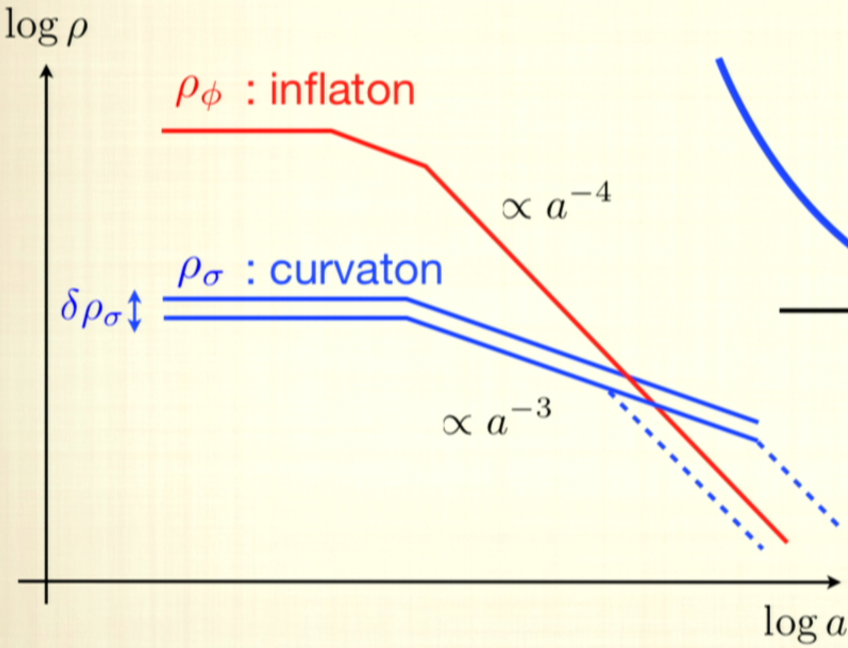
: a light field with negligible energy density during inflation

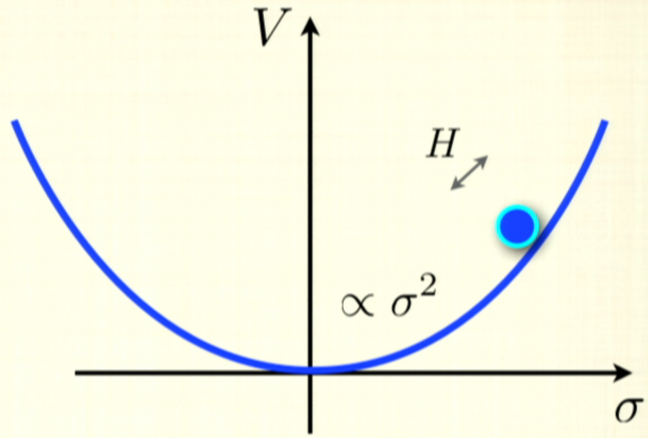




The Quadratic Curvaton Scenario

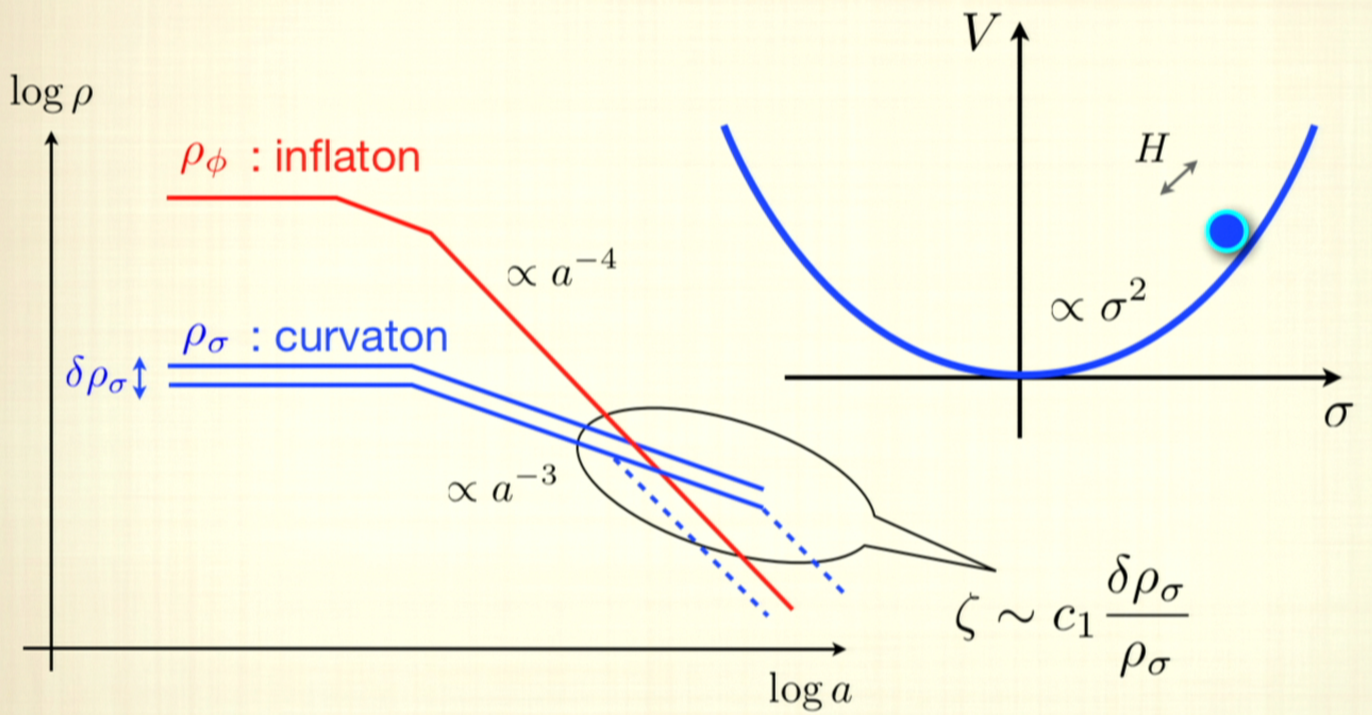
: a light field with negligible energy density during inflation



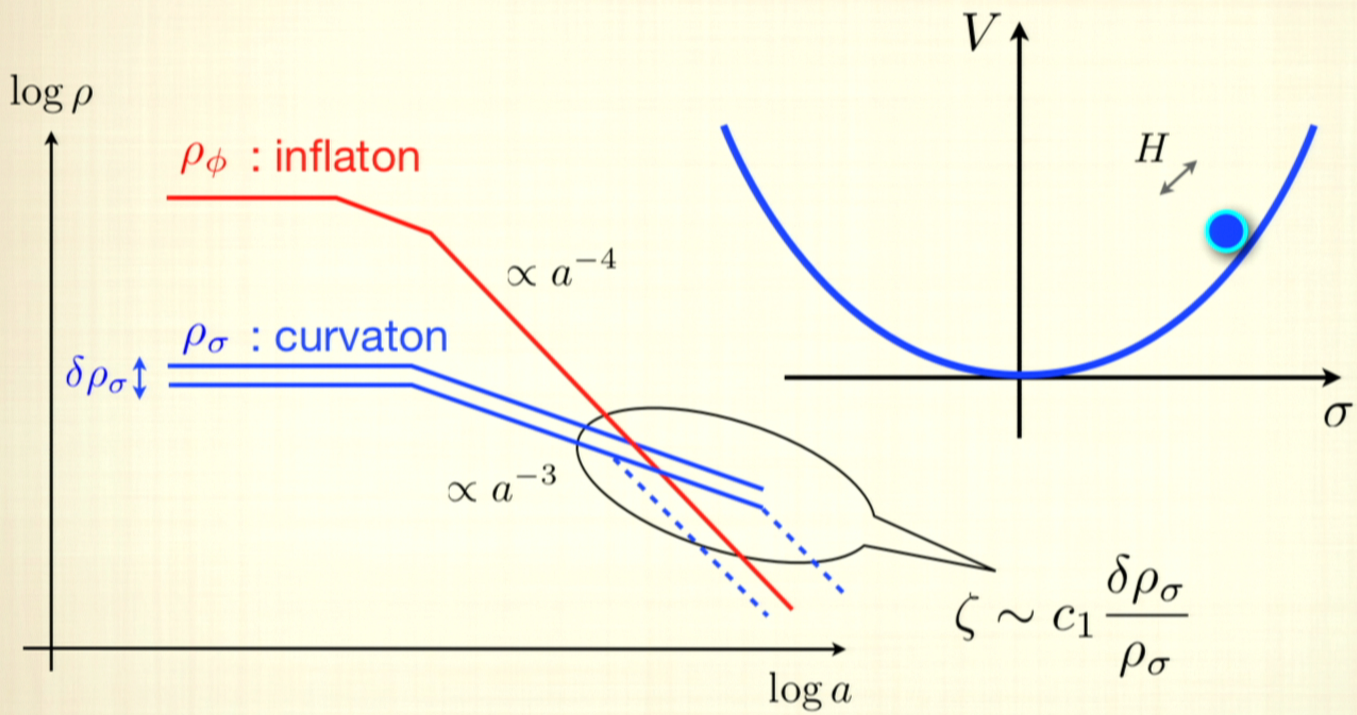


The Quadratic Curvaton Scenario

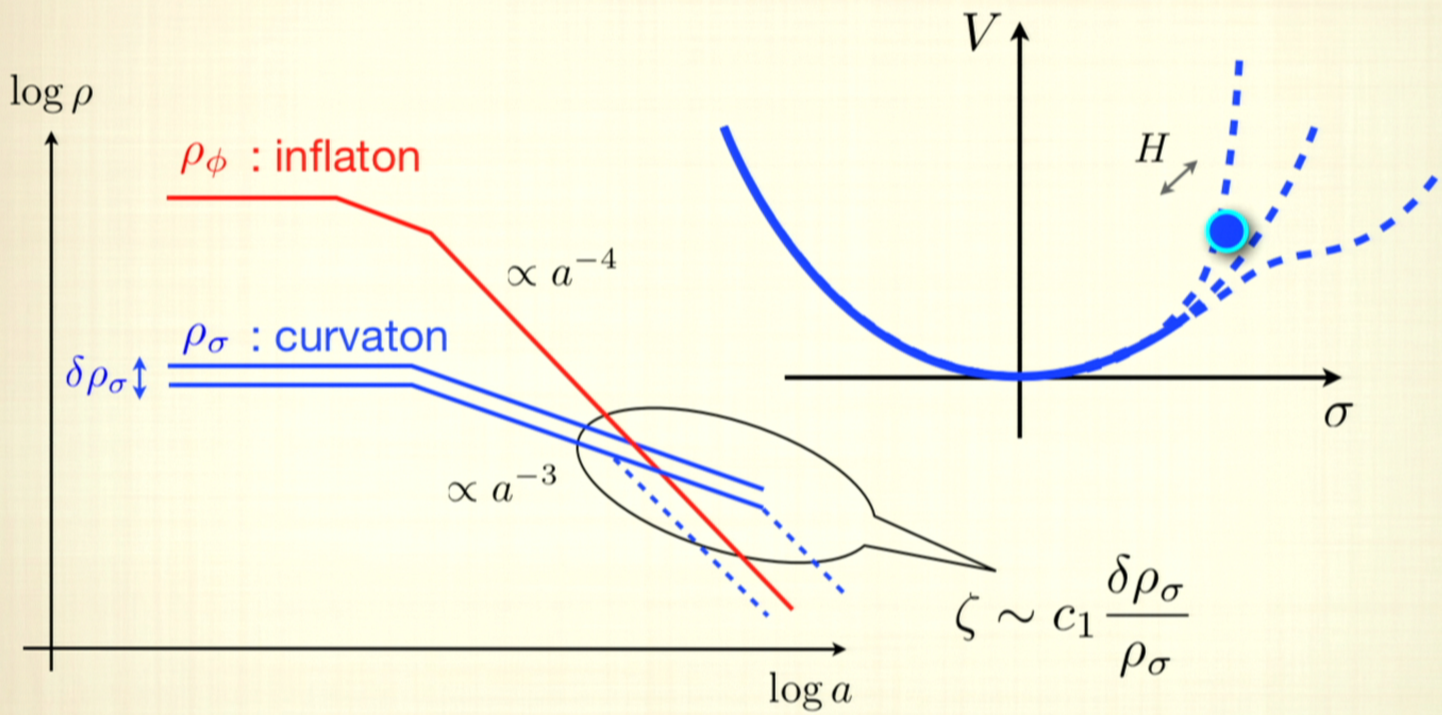
: a light field with negligible energy density during inflation



Curvatons with Arbitrary Potentials

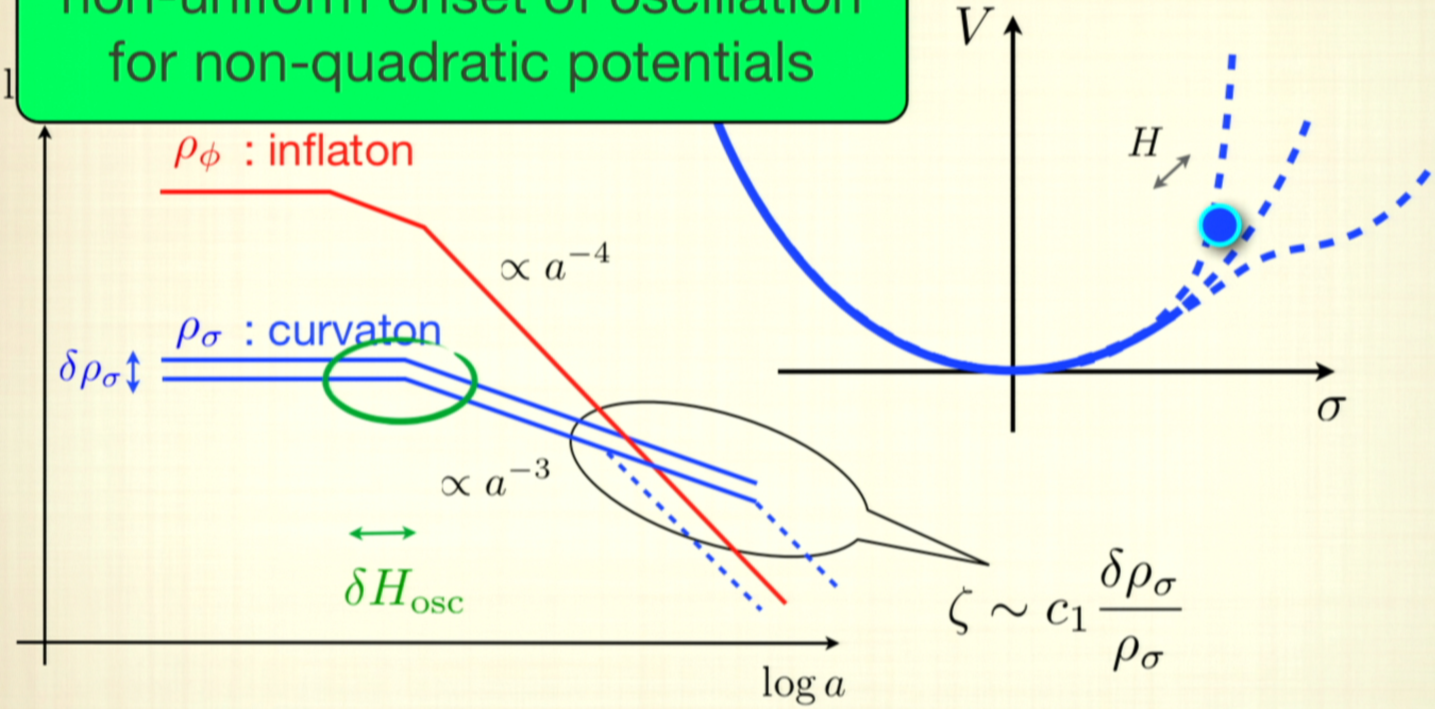


Curvatons with Arbitrary Potentials



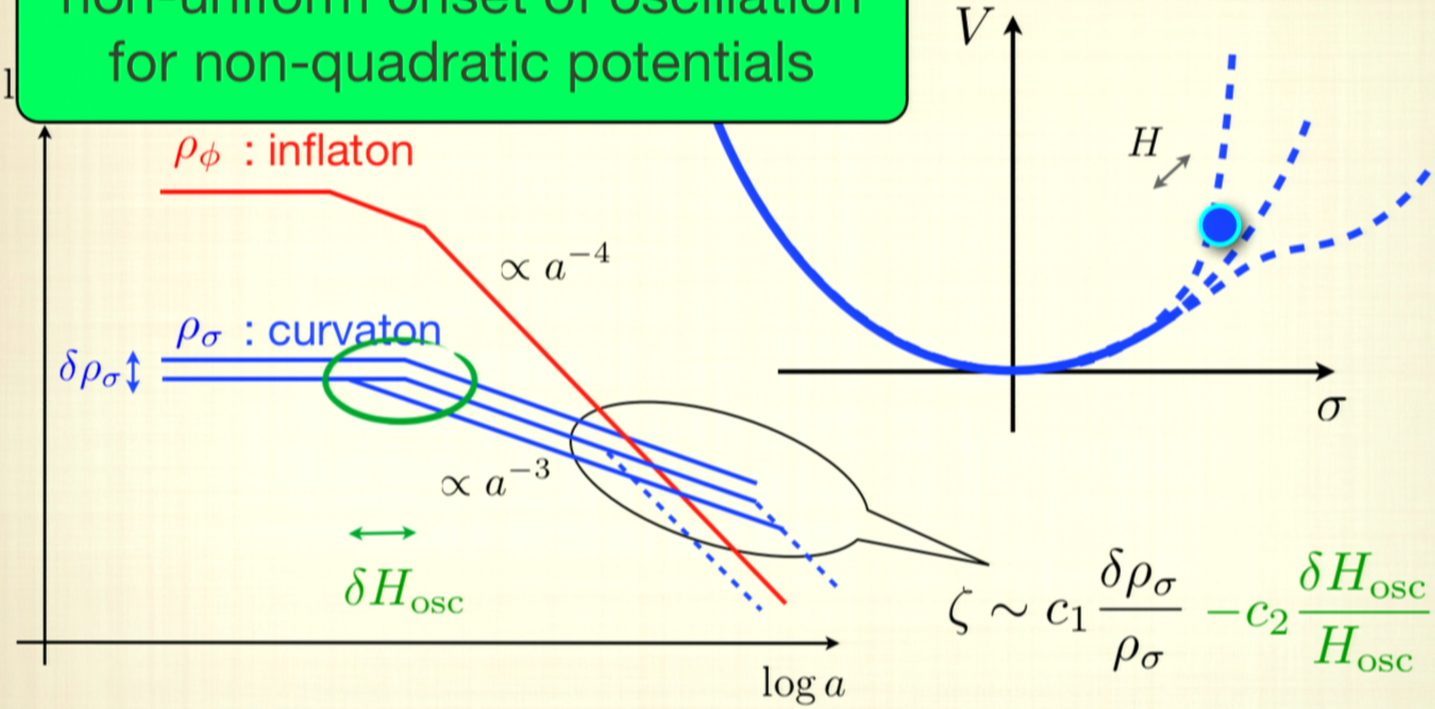
Curvatons with Arbitrary Potentials

non-uniform onset of oscillation for non-quadratic potentials



Curvatons with Arbitrary Potentials

non-uniform onset of oscillation
for non-quadratic potentials



$$\zeta \sim c_1 \frac{\delta\rho_\sigma}{\rho_\sigma} - c_2 \frac{\delta H_{\rm osc}}{H_{\rm osc}}$$

Additional contributions to the density perturbations!

Density Perturbations

$$\mathcal{P}_\zeta = \left(\frac{\partial \mathcal{N}}{\partial \sigma_*} \frac{H_*}{2\pi} \right)^2$$

$$\frac{\partial \mathcal{N}}{\partial \sigma_*} = \frac{r}{4+3r} \left(1 - X(\sigma_{\mathrm{osc}})\right)^{-1} \left\{ \frac{V'(\sigma_{\mathrm{osc}})}{V(\sigma_{\mathrm{osc}})} - \frac{3X(\sigma_{\mathrm{osc}})}{\sigma_{\mathrm{osc}}} \right\} \frac{V'(\sigma_{\mathrm{osc}})}{V'(\sigma_*)}$$

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

Density Perturbations

$$\mathcal{P}_\zeta = \left(\frac{\partial \mathcal{N}}{\partial \sigma_*} \frac{H_*}{2\pi} \right)^2$$

$$\frac{\partial \mathcal{N}}{\partial \sigma_*} = \frac{r}{4+3r} \left(1 - X(\sigma_{\rm osc})\right)^{-1} \left\{ \frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}} \right\} \frac{V'(\sigma_{\rm osc})}{V'(\sigma_*)}$$

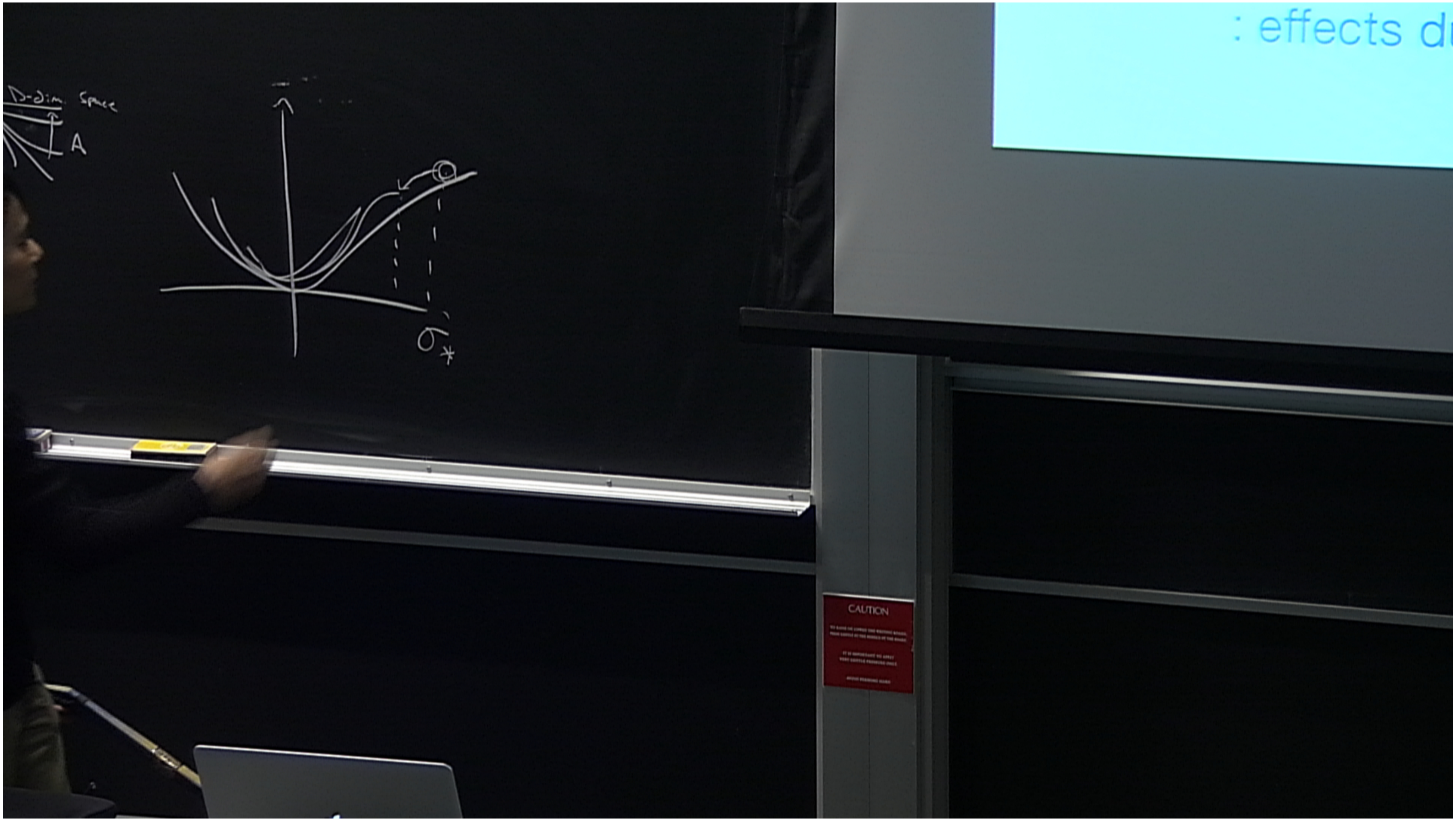
$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

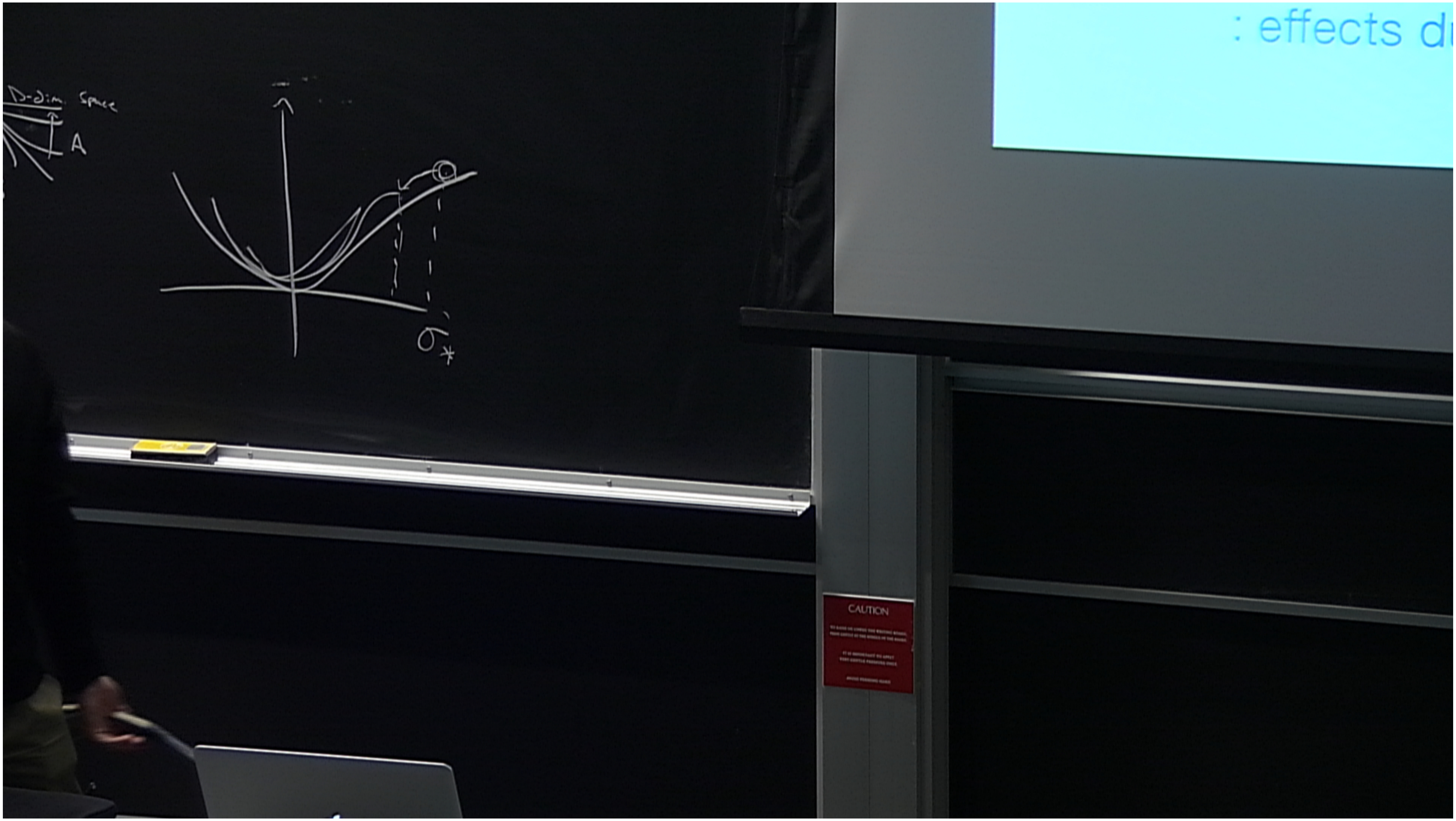
$*$: @ horizon exit

osc : @ onset of curvaton oscillation

$$X(\sigma_{\rm osc}) \equiv \frac{1}{2(c-3)} \left(\frac{\sigma_{\rm osc} V''(\sigma_{\rm osc})}{V'(\sigma_{\rm osc})} - 1 \right)$$

: effects due to non-uniform onset of oscillation


D-dim. space
A
: effects d
CAUTION


D-dim. Space
A
: effects d
CAUTION

Density Perturbations

$$\mathcal{P}_\zeta = \left(\frac{\partial \mathcal{N}}{\partial \sigma_*} \frac{H_*}{2\pi} \right)^2$$

$$\frac{\partial \mathcal{N}}{\partial \sigma_*} = \frac{r}{4+3r} \left(1 - X(\sigma_{\rm osc})\right)^{-1} \left\{ \frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}} \right\} \frac{V'(\sigma_{\rm osc})}{V'(\sigma_*)}$$

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

$$X(\sigma_{\rm osc}) \equiv \frac{1}{2(c-3)} \left(\frac{\sigma_{\rm osc} V''(\sigma_{\rm osc})}{V'(\sigma_{\rm osc})} - 1 \right)$$

: effects due to non-uniform onset of oscillation

Density Perturbations

$$\mathcal{P}_\zeta = \left(\frac{\partial \mathcal{N}}{\partial \sigma_*} \frac{H_*}{2\pi} \right)^2$$

$$\frac{\partial \mathcal{N}}{\partial \sigma_*} = \frac{r}{4+3r} (1 - X(\sigma_{\rm osc}))^{-1} \left\{ \frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}} \right\} \frac{V'(\sigma_{\rm osc})}{V'(\sigma_*)}$$

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

spectral index $\quad n_s - 1 \equiv \frac{d \ln \mathcal{P}_\zeta}{d \ln k} = \frac{2}{3} \frac{V''(\sigma_*)}{H_*^2} + 2 \frac{\dot{H}_*}{H_*^2}$

observational data $= -0.032 \pm 0.012$ (WMAP7, 68%CL)

requires a tachyonic curvaton, or rather large $\dot{H}$

Non-Gaussianity

$$f_{\mathrm{NL}} = \frac{40(1+r)}{3r(4+3r)} + \frac{5(4+3r)}{6r}\left\{\frac{V'(\sigma_{\mathrm{osc}})}{V(\sigma_{\mathrm{osc}})} - \frac{3X(\sigma_{\mathrm{osc}})}{\sigma_{\mathrm{osc}}}\right\}^{-1}\Bigg[(1-X(\sigma_{\mathrm{osc}}))^{-1}X'(\sigma_{\mathrm{osc}})$$

$$+\left\{\frac{V'(\sigma_{\mathrm{osc}})}{V(\sigma_{\mathrm{osc}})} - \frac{3X(\sigma_{\mathrm{osc}})}{\sigma_{\mathrm{osc}}}\right\}^{-1}\left\{\frac{V''(\sigma_{\mathrm{osc}})}{V(\sigma_{\mathrm{osc}})} - \frac{V'(\sigma_{\mathrm{osc}})^2}{V(\sigma_{\mathrm{osc}})^2} - \frac{3X'(\sigma_{\mathrm{osc}})}{\sigma_{\mathrm{osc}}} + \frac{3X(\sigma_{\mathrm{osc}})}{\sigma_{\mathrm{osc}}^2}\right\}$$

$$+\frac{V''(\sigma_{\mathrm{osc}})}{V'(\sigma_{\mathrm{osc}})} - (1-X(\sigma_{\mathrm{osc}}))\frac{V''(\sigma_*)}{V'(\sigma_{\mathrm{osc}})}\Bigg]$$

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

Non-Gaussianity

$$f_{\rm NL} = \frac{40(1+r)}{3r(4+3r)} + \frac{5(4+3r)}{6r}\left\{\frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}}\right\}^{-1}\left[(1-X(\sigma_{\rm osc}))^{-1}X'(\sigma_{\rm osc}) \right.$$

$$+\left\{\frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}}\right\}^{-1}\left\{\frac{V''(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{V'(\sigma_{\rm osc})^2}{V(\sigma_{\rm osc})^2} - \frac{3X'(\sigma_{\rm osc})}{\sigma_{\rm osc}} + \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}^2}\right\}$$

$$\left. + \frac{V''(\sigma_{\rm osc})}{V'(\sigma_{\rm osc})} - (1-X(\sigma_{\rm osc}))\frac{V''(\sigma_*)}{V'(\sigma_{\rm osc})}\right]$$

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

cf. quadratic curvatons

$$f_{\rm NL} = \frac{5}{12}\left(-3 + \frac{4}{r} + \frac{8}{4+3r}\right)$$

$f_{\rm NL} \gg 1$ only for curvatons decaying when subdominant ($r \ll 1$)

Non-Gaussianity

$$f_{\rm NL} = \frac{40(1+r)}{3r(4+3r)} + \frac{5(4+3r)}{6r}\left\{\frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}}\right\}^{-1}\Big[(1-X(\sigma_{\rm osc}))^{-1}X'(\sigma_{\rm osc})$$

Large $f_{\rm NL}$ (with either sign) possible for both dominant/subdominant curvatons!

$r \equiv \frac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

cf. quadratic curvatons

$$f_{\rm NL} = \frac{5}{12}\left(-3 + \frac{4}{r} + \frac{8}{4+3r}\right)$$

$f_{\rm NL} \gg 1$ only for curvatons decaying when subdominant ($r \ll 1$)

Non-Gaussianity

$$f_{\rm NL} = \frac{40(1+r)}{3r(4+3r)} + \frac{5(4+3r)}{6r}\left\{\frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}}\right\}^{-1}\Bigg[(1-X(\sigma_{\rm osc}))^{-1}X'(\sigma_{\rm osc})$$
$$+\left\{\frac{V'(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}}\right\}^{-1}\left\{\frac{V''(\sigma_{\rm osc})}{V(\sigma_{\rm osc})} - \frac{V'(\sigma_{\rm osc})^2}{V(\sigma_{\rm osc})^2} - \frac{3X'(\sigma_{\rm osc})}{\sigma_{\rm osc}} + \frac{3X(\sigma_{\rm osc})}{\sigma_{\rm osc}^2}\right\}$$
$$+\frac{V''(\sigma_{\rm osc})}{V'(\sigma_{\rm osc})} - (1-X(\sigma_{\rm osc}))\frac{V''(\sigma_*)}{V'(\sigma_{\rm osc})}\Bigg]$$

$r \equiv \dfrac{\rho_\sigma}{\rho_r}$ @ curvaton decay

$*$: @ horizon exit

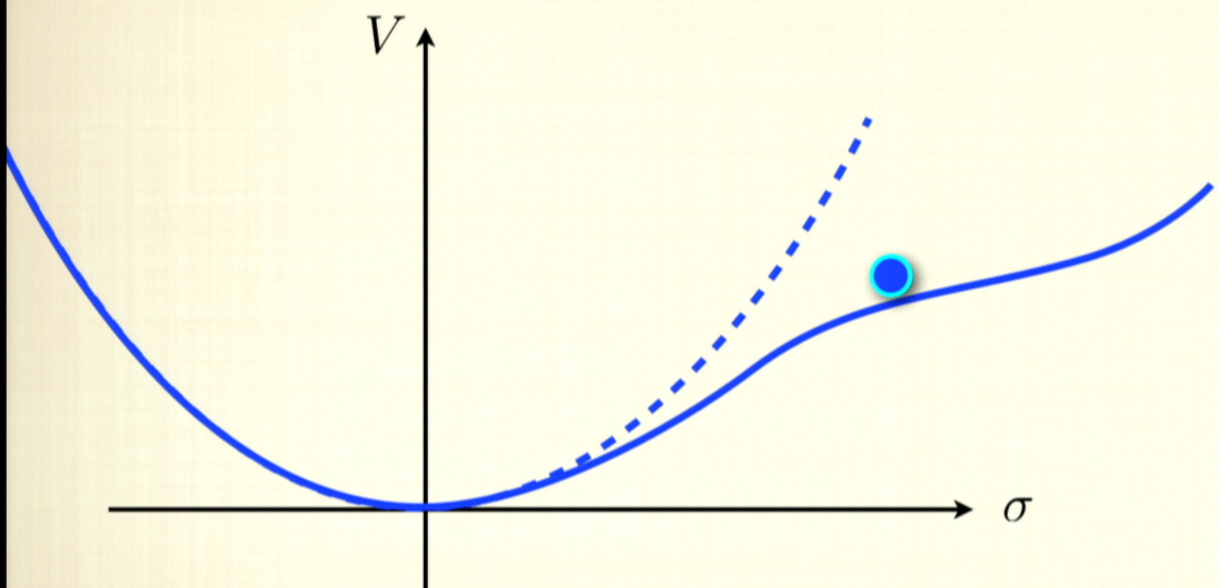
osc : @ onset of curvaton oscillation

cf. quadratic curvatons

$$f_{\rm NL} = \frac{5}{12}\left(-3 + \frac{4}{r} + \frac{8}{4+3r}\right)$$

$f_{\rm NL} \gg 1$ only for curvatons decaying when subdominant ($r \ll 1$)

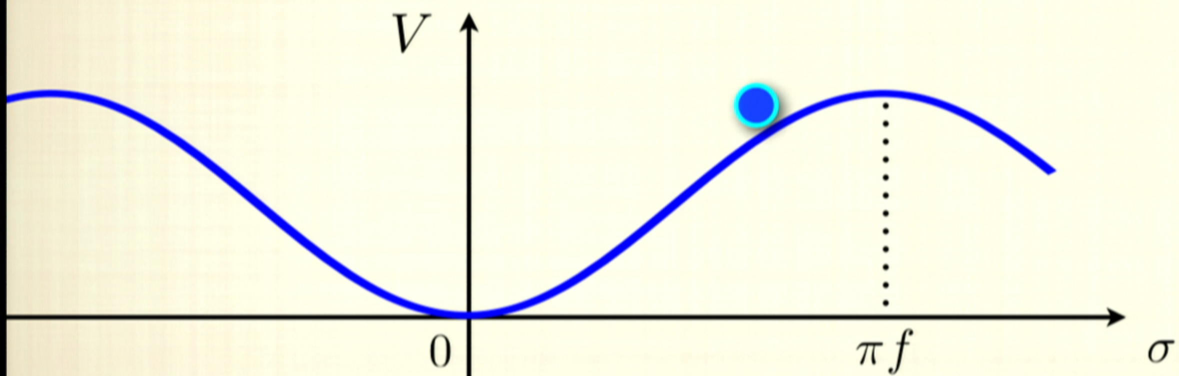
1. Flat Potentials



Effects due to non-uniform onset of oscillation can become significant, leading to strong enhancement of linear-order perturbations & non-Gaussianity.

case study : Curvaton = pseudo-NG boson of a broken U(1) symmetry

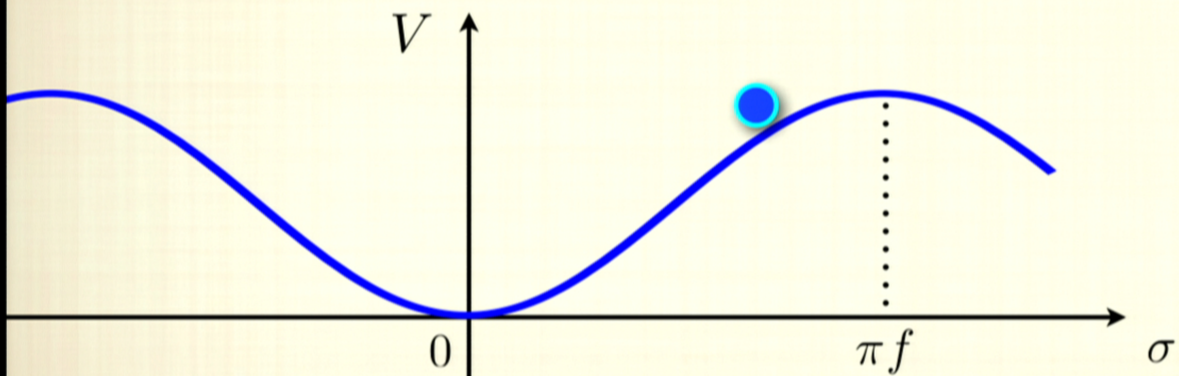
$$V(\sigma) = \Lambda^4 \left[1 - \cos\left(\frac{\sigma}{f}\right)\right]$$



curvaton decay rate : $\Gamma_\sigma \sim \frac{1}{16\pi}\frac{m^3}{f^2} = \frac{1}{16\pi}\frac{\Lambda^6}{f^5}$

case study : Curvaton = pseudo-NG boson of a broken U(1) symmetry

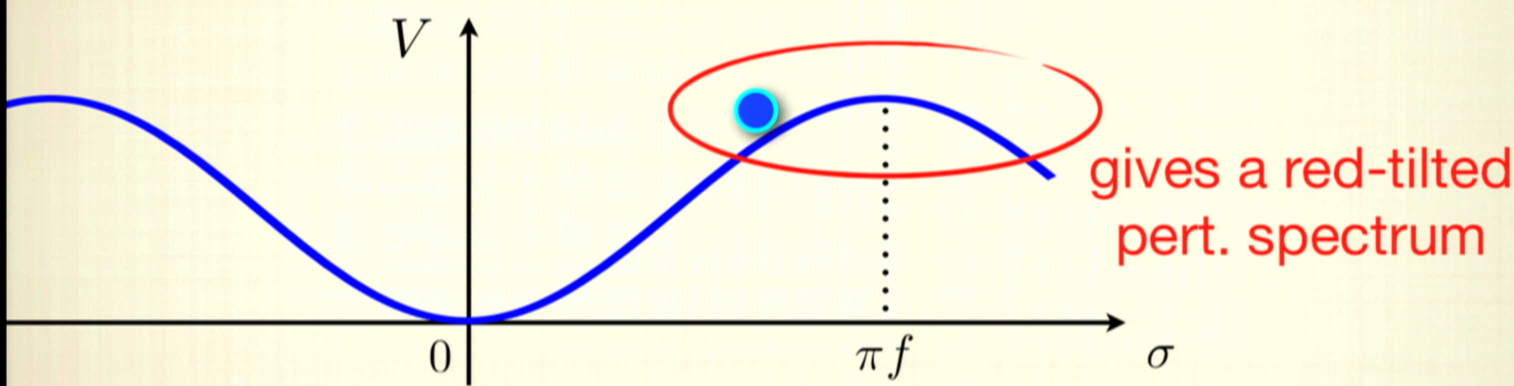
$$V(\sigma) = \Lambda^4 \left[1 - \cos\left(\frac{\sigma}{f}\right)\right]$$



curvaton decay rate : $\Gamma_\sigma \sim \frac{1}{16\pi}\frac{m^3}{f^2} = \frac{1}{16\pi}\frac{\Lambda^6}{f^5}$

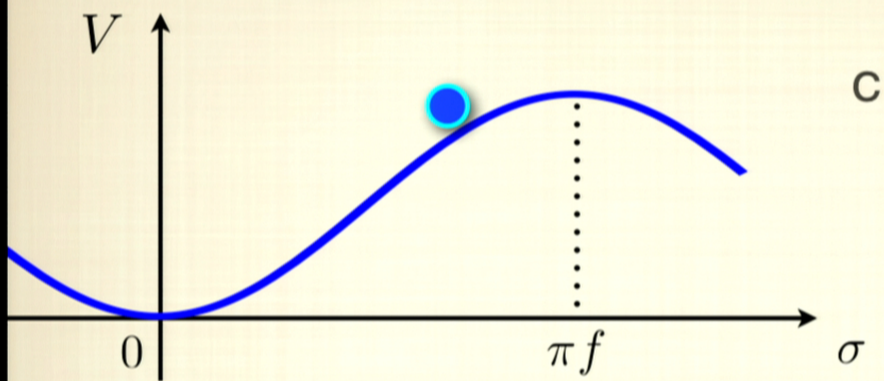
case study : Curvaton = pseudo-NG boson of a broken U(1) symmetry

$$V(\sigma) = \Lambda^4 \left[1 - \cos\left(\frac{\sigma}{f}\right) \right]$$



curvaton decay rate : $\Gamma_\sigma \sim \frac{1}{16\pi}\frac{m^3}{f^2} = \frac{1}{16\pi}\frac{\Lambda^6}{f^5}$

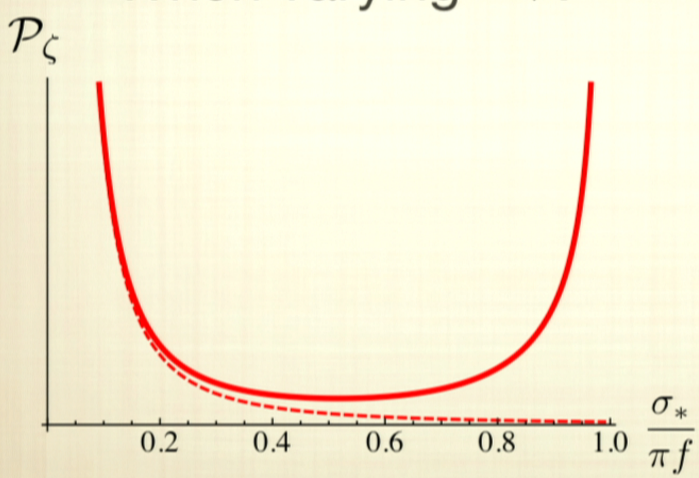
Density Pert. from a NG-Curvaton

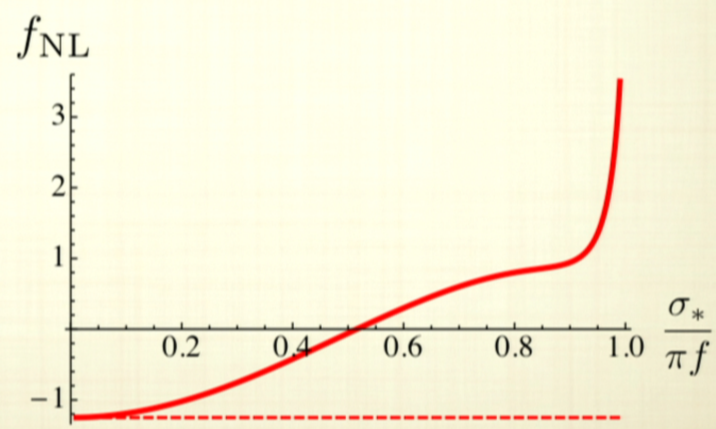


curvaton dominant case,

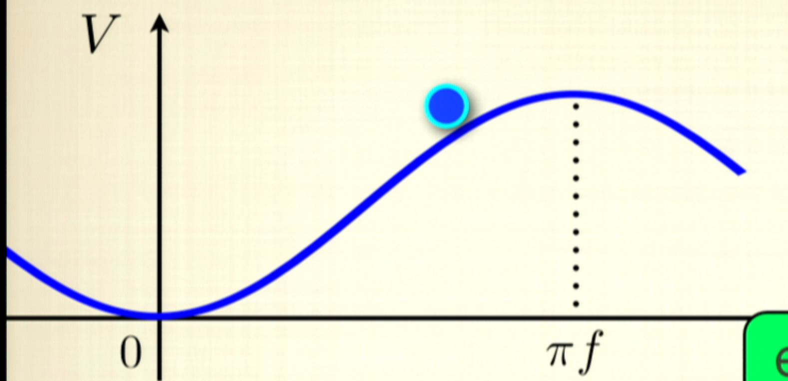
i.e. $r \equiv \left.\frac{\rho_\sigma}{\rho_r}\right|_{\rm dec} \gg 1$

When varying σ_* :





Density Pert. from a NG-Curvaton

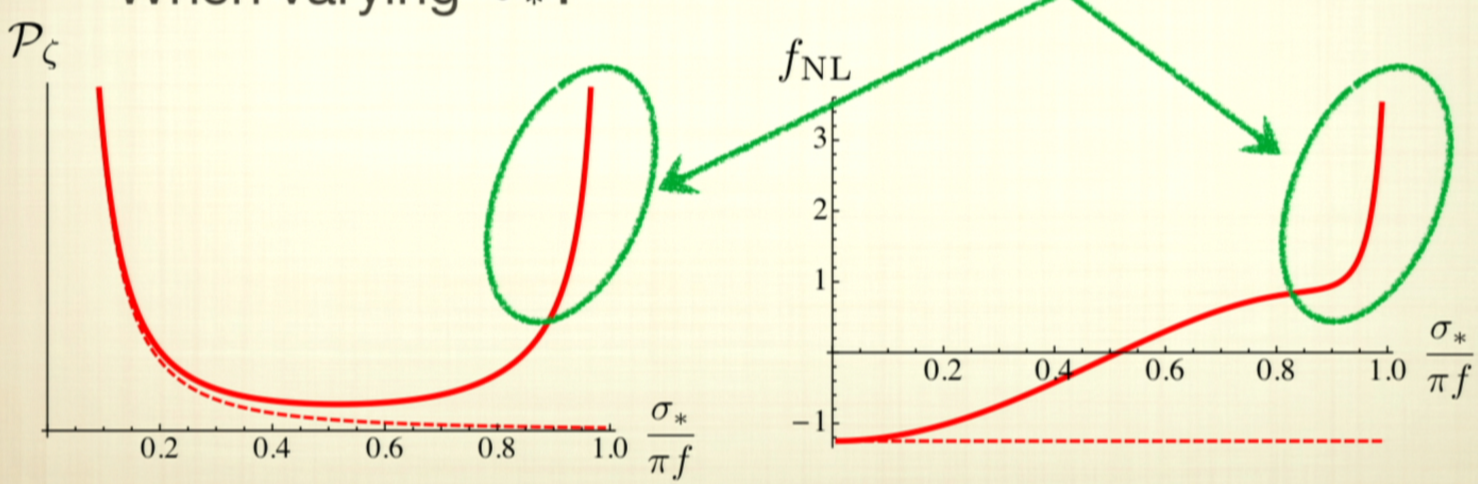


curvaton dominant case,

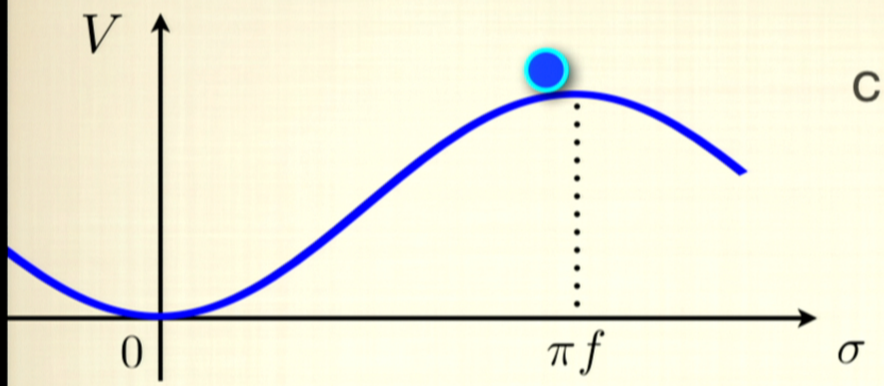
i.e. $r \equiv \left.\frac{\rho_\sigma}{\rho_r}\right|_{\text{dec}} \gg 1$

effects due to non-uniform onset of oscillation

When varying σ_* :



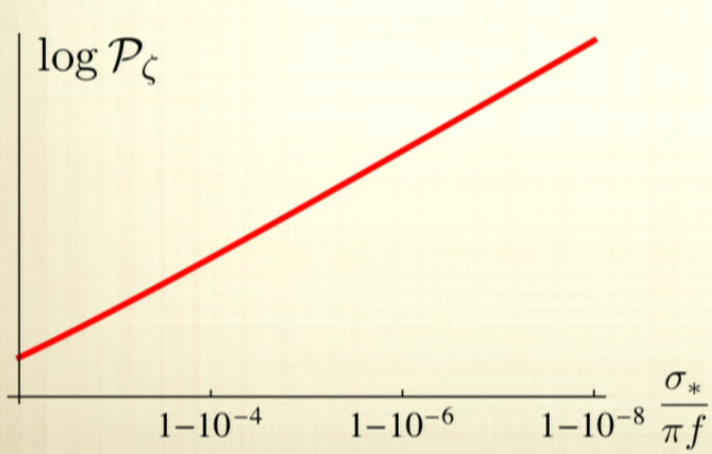
Density Pert. from the Hilltop

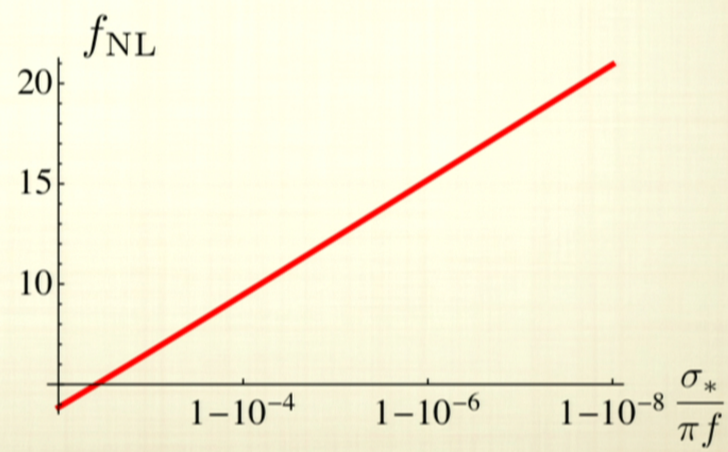


curvaton dominant case,

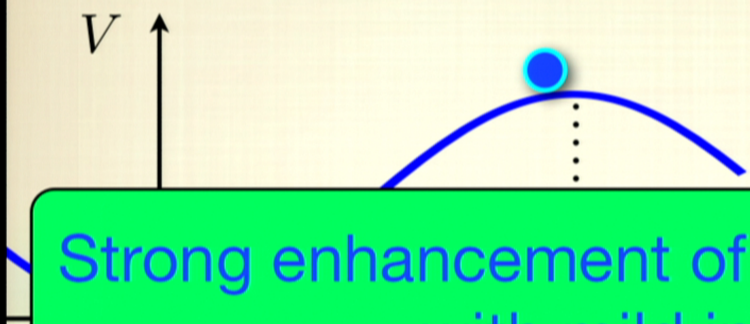
i.e. $r \equiv \left.\frac{\rho_\sigma}{\rho_r}\right|_{\rm dec} \gg 1$

When varying σ_* :



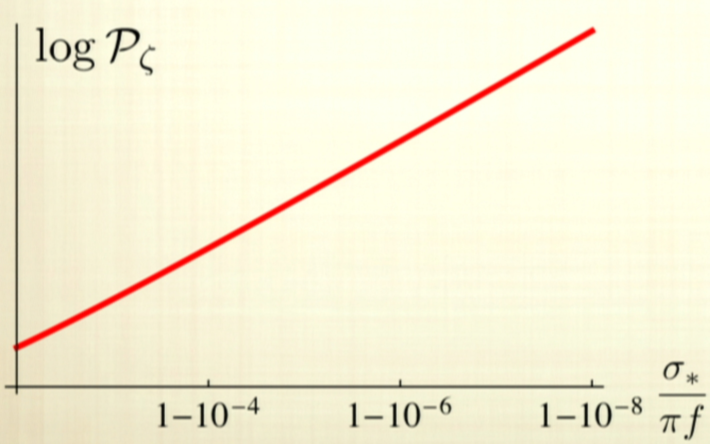


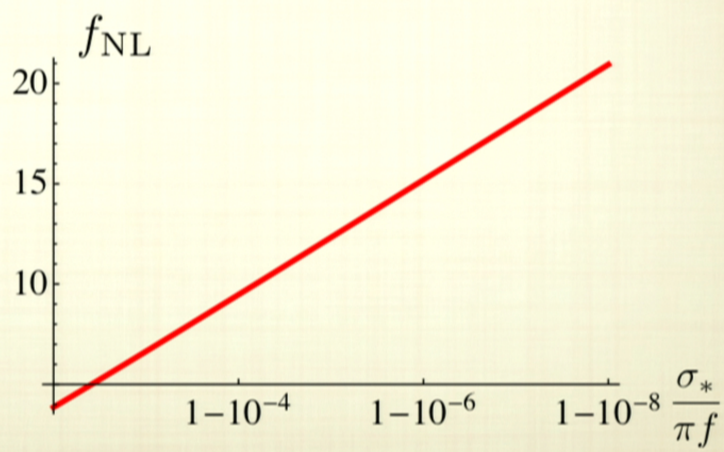
Density Pert. from the Hilltop



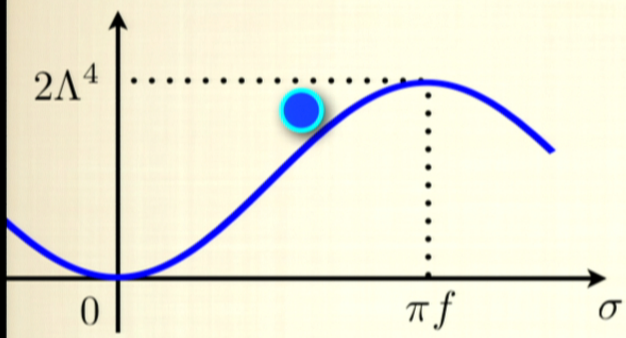
curvaton dominant case,

Strong enhancement of linear-order density pert.
with mild increase of f_{NL}
towards the hilltop.



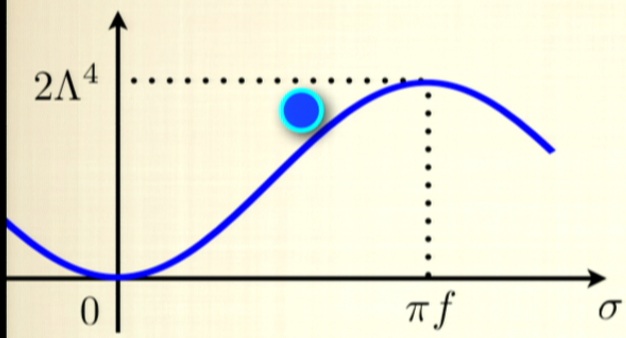


Windows for Inflation/Reheating Scales



$$(f,\ \Lambda,\ H_{\rm inf},\ T_{\rm reh},\ \sigma_*)$$

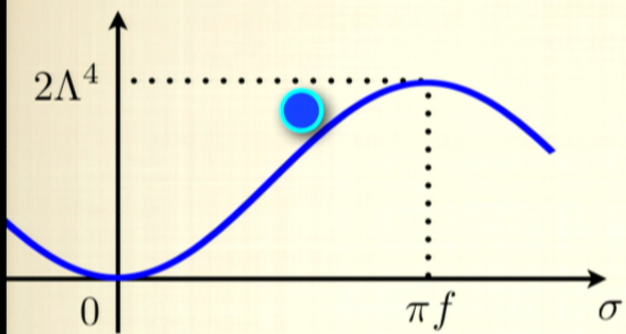
Windows for Inflation/Reheating Scales



$(\sout{f,}\ \sout{\Lambda,}\ H_{\rm inf},\ T_{\rm reh},\ \sigma_*)$

- COBE norm.
- spectral index

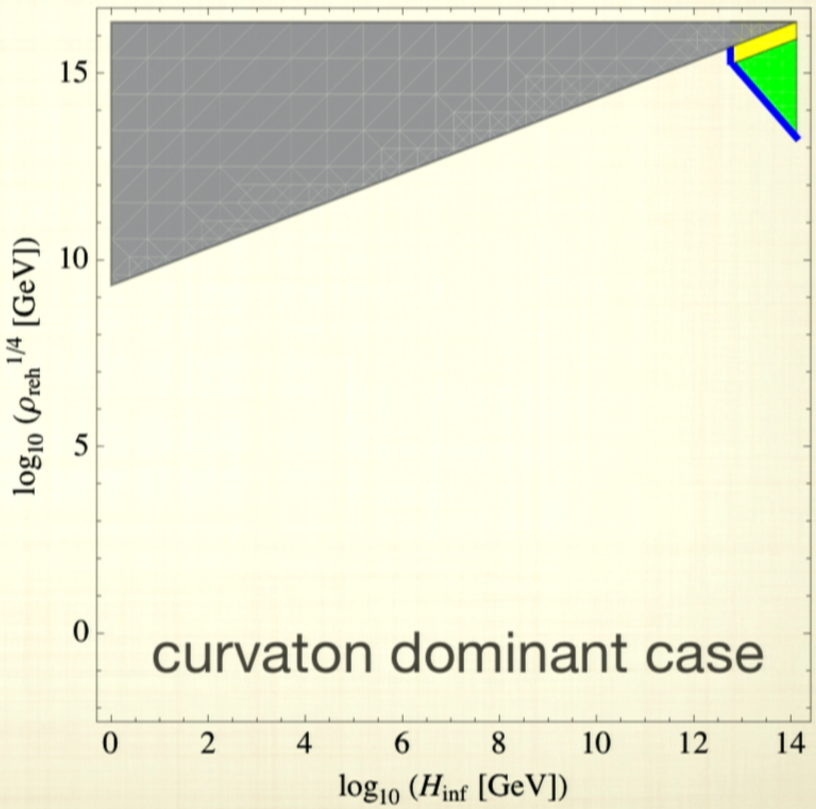
Windows for Inflation/Reheating Scales



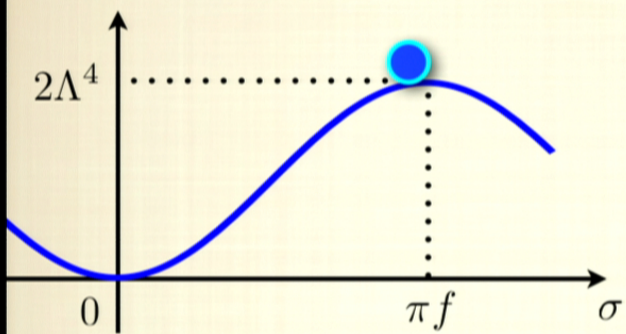
$(\not{f}, \not{\Lambda}, H_{\text{inf}}, T_{\text{reh}}, \sigma_*)$

- COBE norm.
- spectral index

$$\frac{\sigma_*}{\pi f} = \frac{3}{4}$$



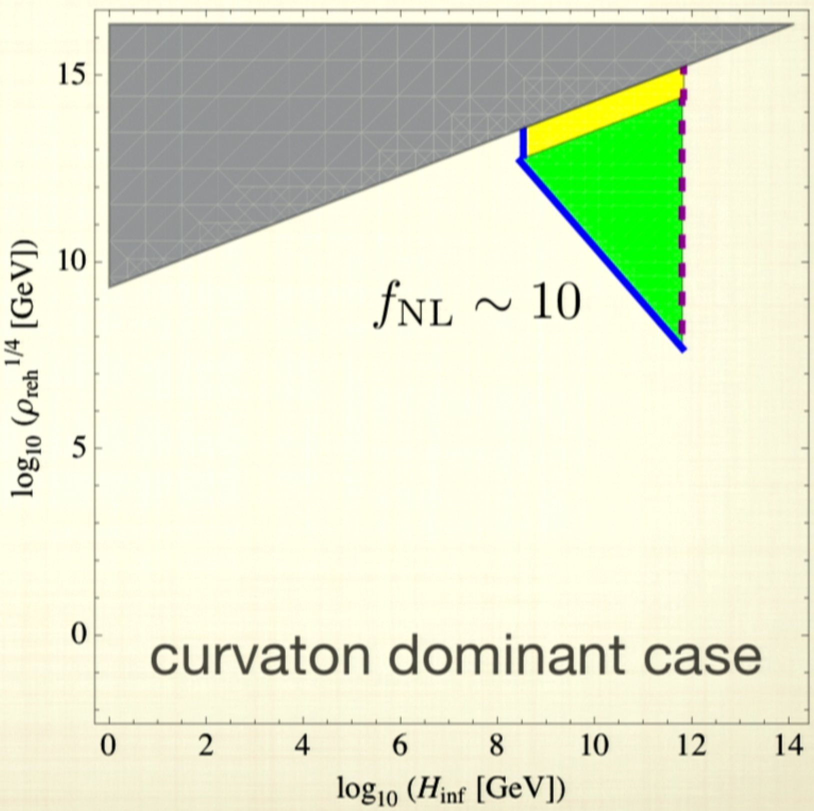
Windows for Inflation/Reheating Scales



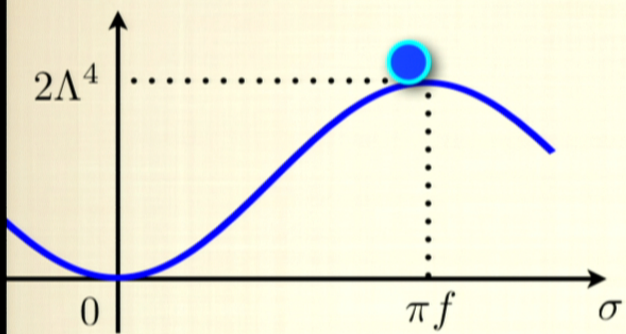
$(\sout{f}, \sout{\Lambda}, H_{\rm inf}, T_{\rm reh}, \sigma_*)$

- COBE norm.
- spectral index

$$\frac{\sigma_*}{\pi f} = 1 - 10^{-4}$$



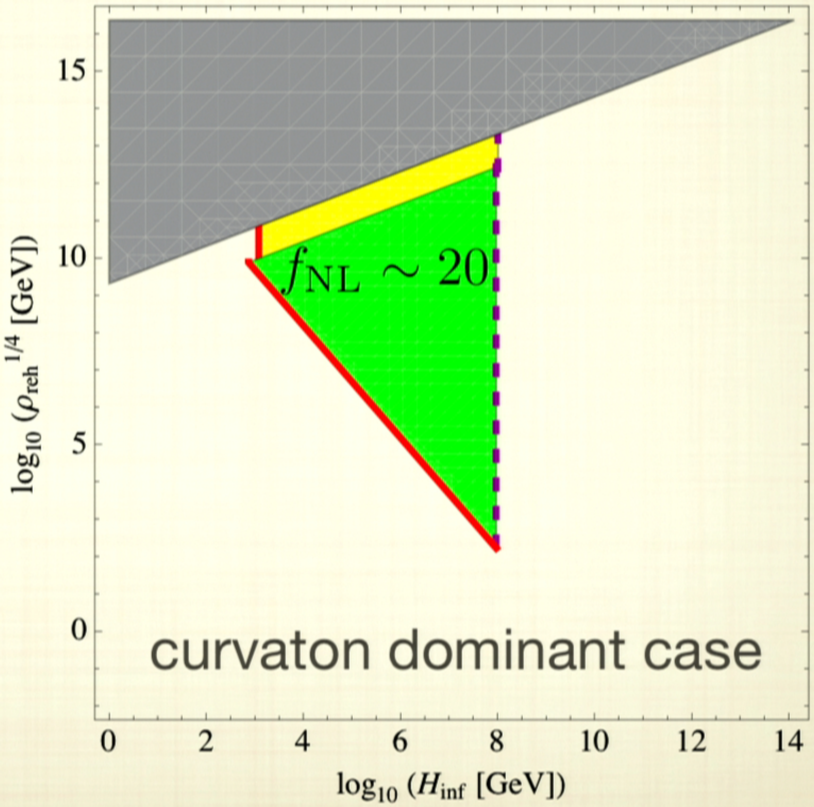
Windows for Inflation/Reheating Scales



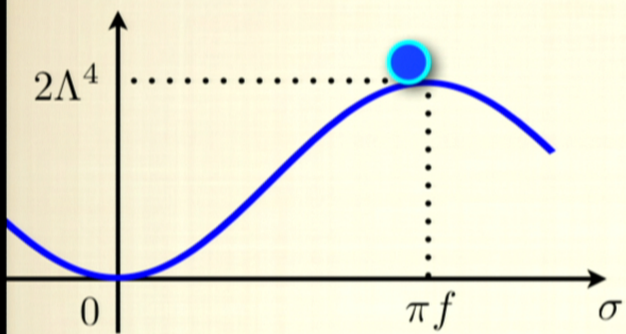
$(\not{f}, \not{\Lambda}, H_{\rm inf}, T_{\rm reh}, \sigma_*)$

- COBE norm.
- spectral index

$$\frac{\sigma_*}{\pi f} = 1 - 10^{-8}$$



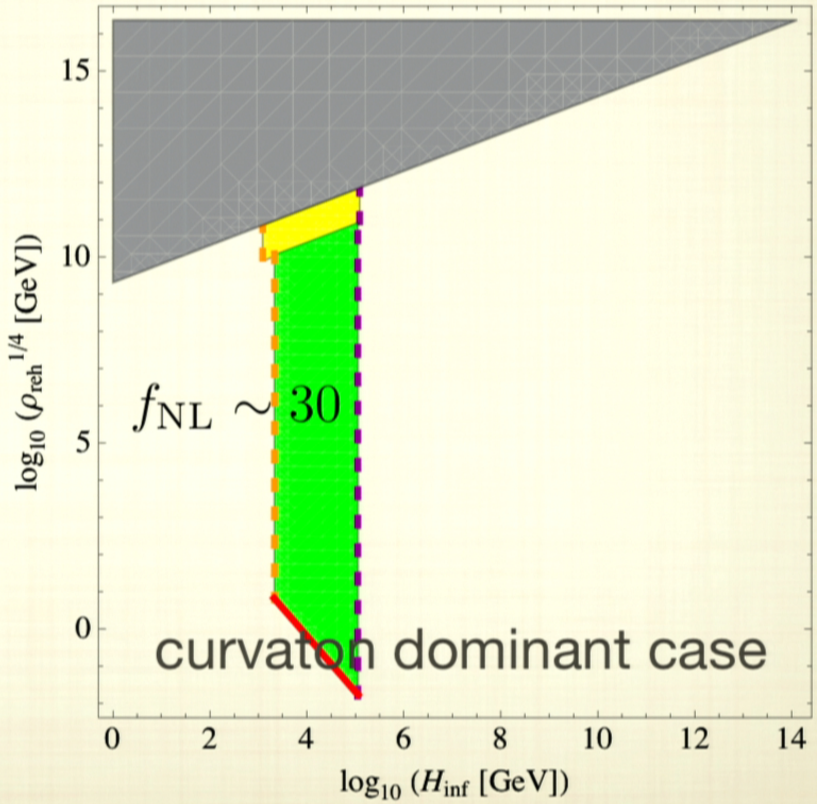
Windows for Inflation/Reheating Scales



$(\sout{f}, \sout{\Lambda}, H_{\rm inf}, T_{\rm reh}, \sigma_*)$

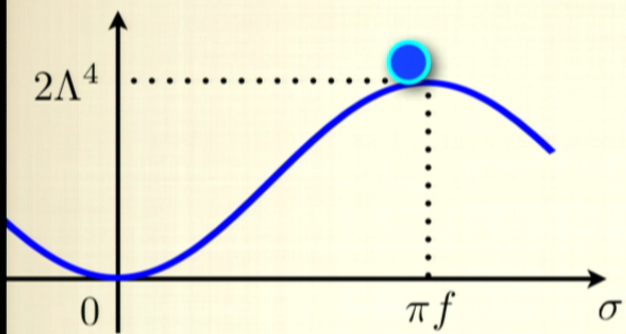
- COBE norm.
- spectral index

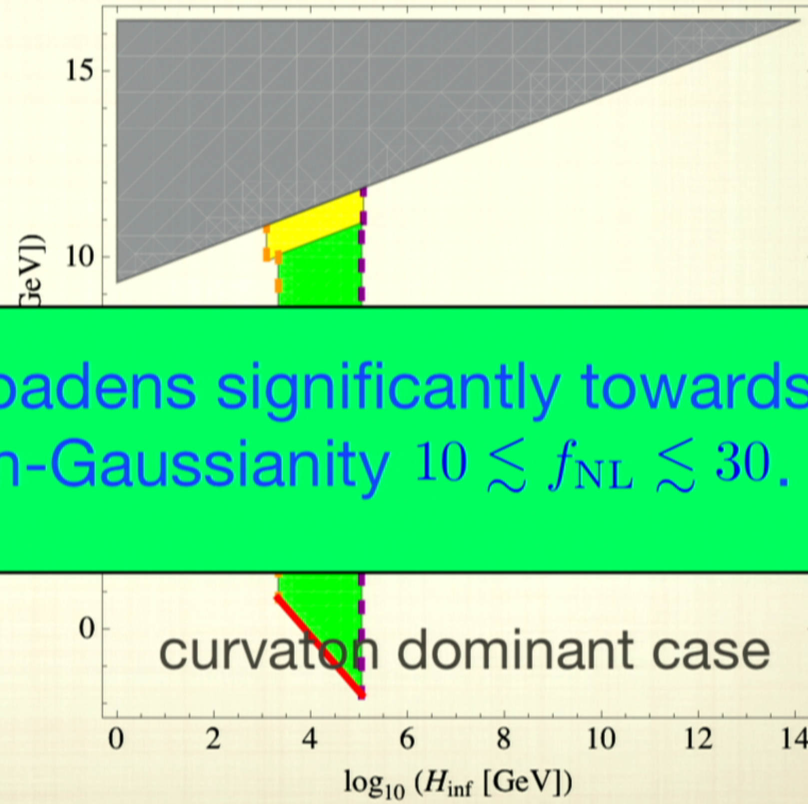
$$\frac{\sigma_*}{\pi f} = 1 - 10^{-11}$$



Windows for Inflation/Reheating Scales

$$\frac{\sigma_*}{\pi f} = 1 - 10^{-11}$$

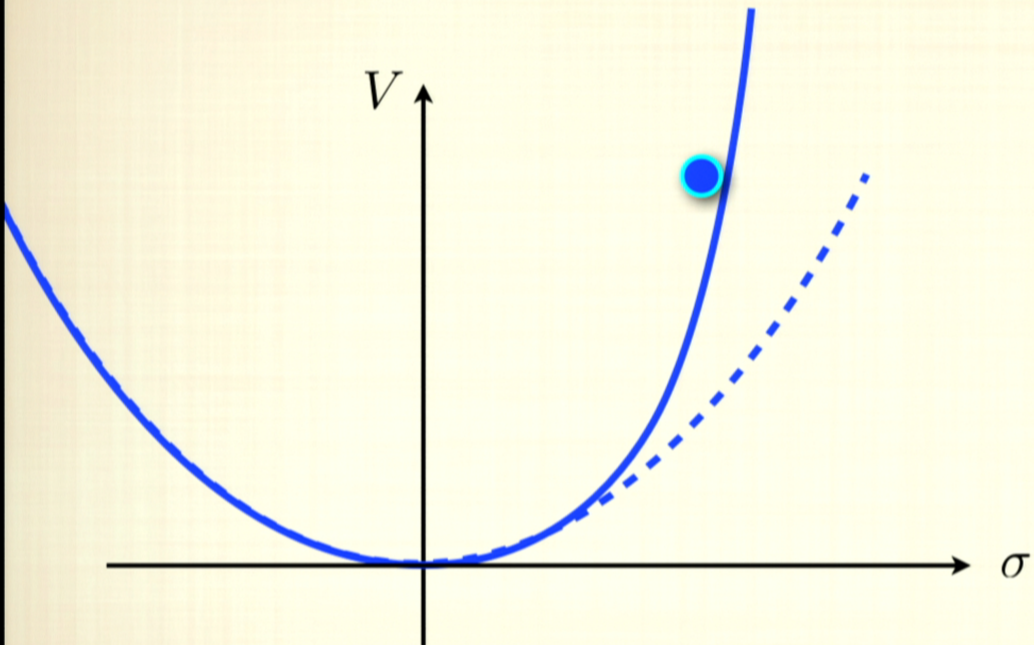




Allowed window broadens significantly towards the hilltop, with non-Gaussianity $10 \lesssim f_{\rm NL} \lesssim 30$.

- COBE norm.
- spectral index

2. Steep Potentials



Curvaton rolling along the steep potential can lead to strongly scale-dependent non-Gaussianity.

Running of f_{NL}

$$n_{f_{\rm NL}} \equiv \frac{d \ln |f_{\rm NL}|}{d \ln k}$$

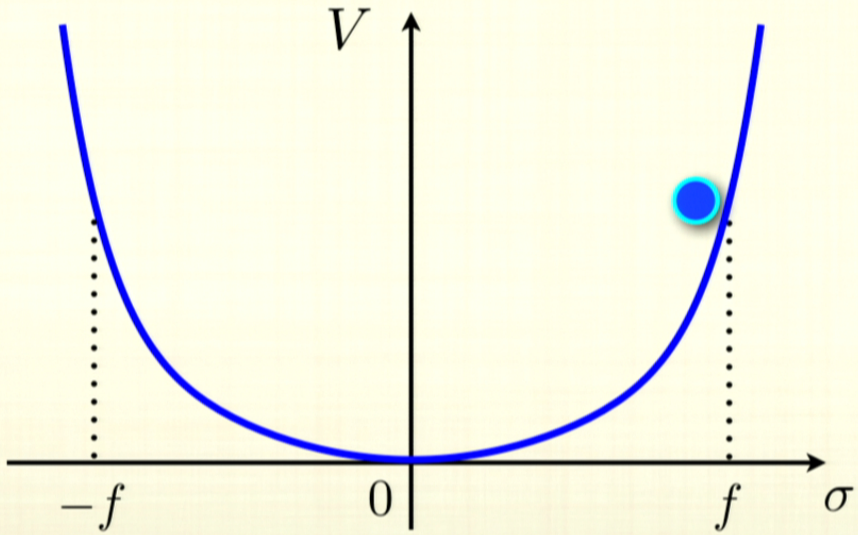
$$= \frac{1}{f_{\rm NL}} \frac{5}{18} \left(\frac{\partial \mathcal{N}}{\partial \sigma_*} \right)^{-1} \frac{V'''(\sigma_*)}{H_*^2}$$

PLANCK detection limit : $|n_{f_{\rm NL}} f_{\rm NL}| \gtrsim 5$

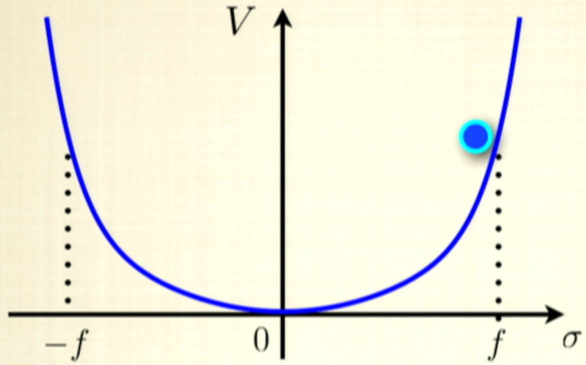
(for fiducial values $f_{\rm NL} = 50, \ n_{f_{\rm NL}} = 0$, Sefusatti et al. '09)

Self-Interacting Curvatons

$$V(\sigma) = \Lambda^4 \left[\left(\frac{\sigma}{f}\right)^2 + \left(\frac{\sigma}{f}\right)^m \right]$$



Self-Interacting Curvatons



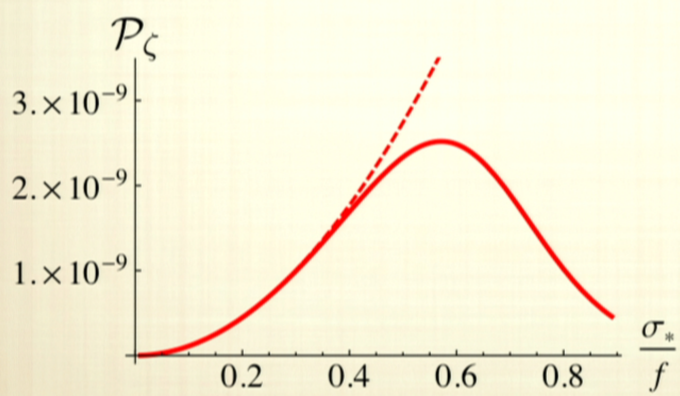
$$V(\sigma) = \Lambda^4 \left[\left(\frac{\sigma}{f}\right)^2 + \left(\frac{\sigma}{f}\right)^8 \right]$$

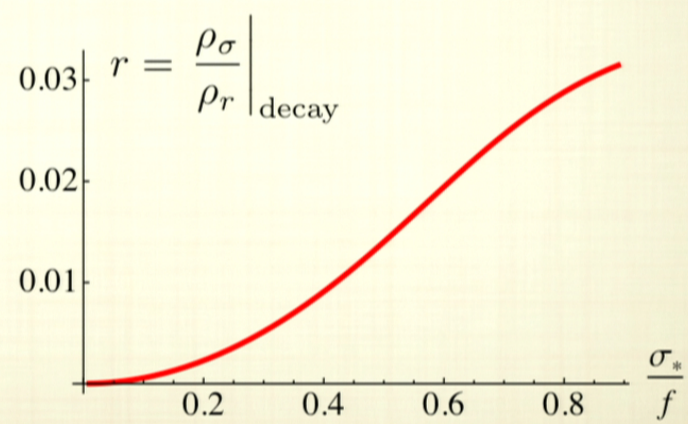
ex.) $\Lambda \sim 10^{12}\mathrm{GeV}$ $\quad f \sim 10^{13}\mathrm{GeV}$

$H_{\mathrm{inf}} \sim 10^{12}\mathrm{GeV}$ $\quad T_{\mathrm{reh}} \sim 10^{11}\mathrm{GeV}$

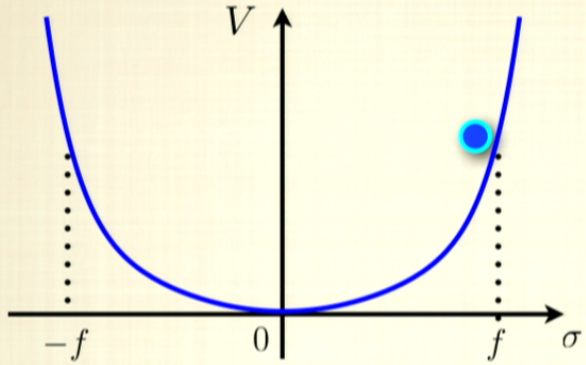
$T_{\mathrm{dec}} \sim 100\mathrm{GeV}$

When varying σ_* :





Self-Interacting Curvatons



$$V(\sigma) = \Lambda^4 \left[\left(\frac{\sigma}{f}\right)^2 + \left(\frac{\sigma}{f}\right)^8 \right]$$

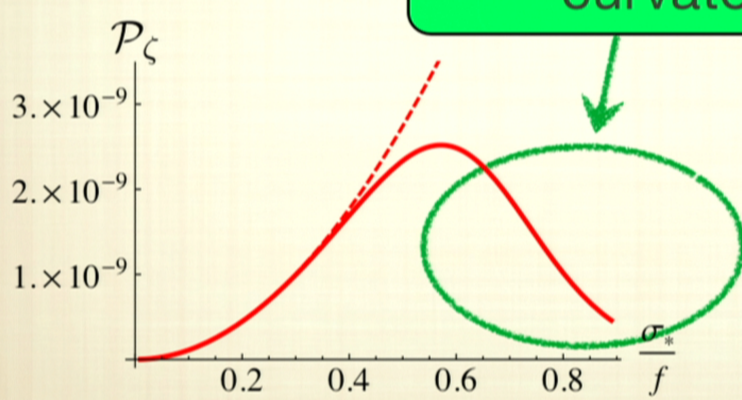
ex.) $\Lambda \sim 10^{12}\mathrm{GeV}$ $\quad f \sim 10^{13}\mathrm{GeV}$

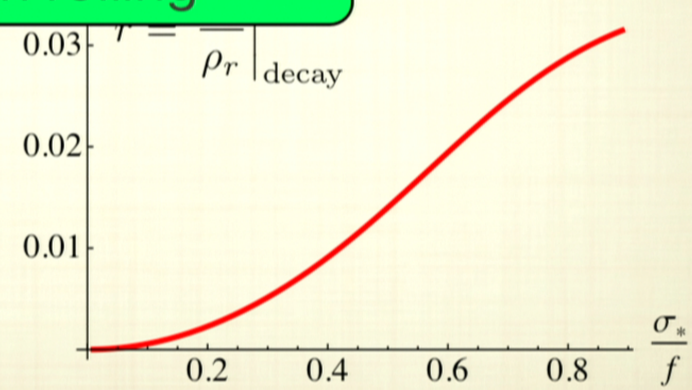
$H_{\mathrm{inf}} \sim 10^{12}\mathrm{GeV}$ $\quad T_{\mathrm{reh}} \sim 10^{11}\mathrm{GeV}$

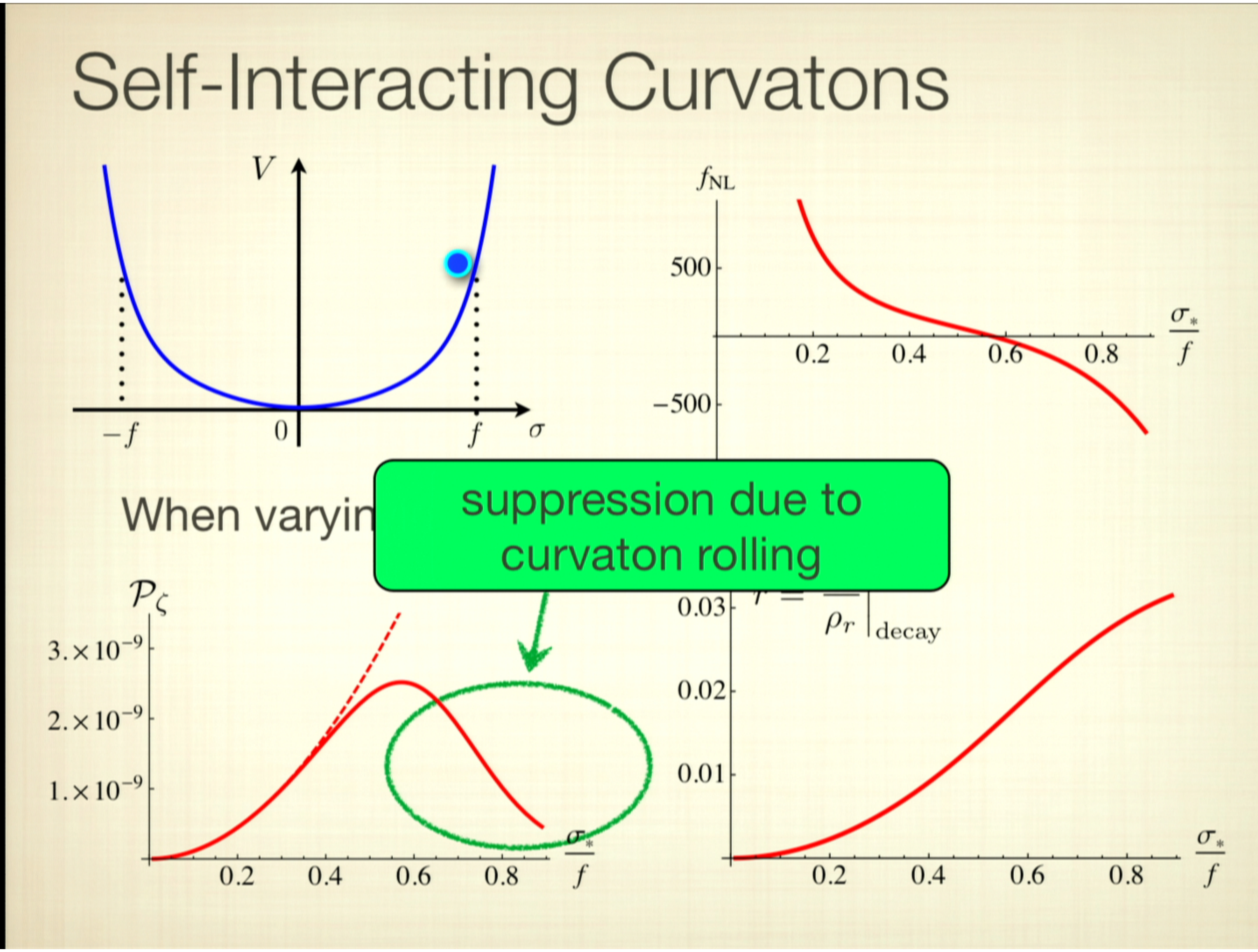
$T_{\mathrm{dec}} \sim 100\mathrm{GeV}$

When varyin

suspression due to curvaton rolling

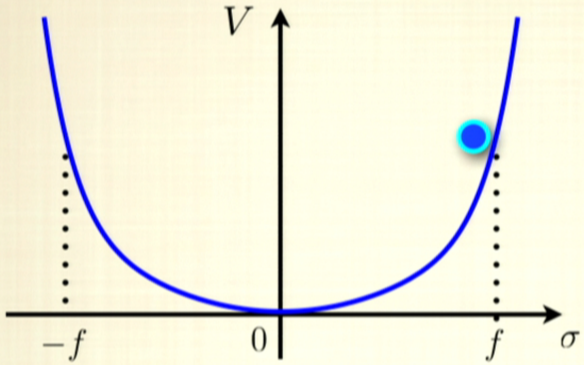


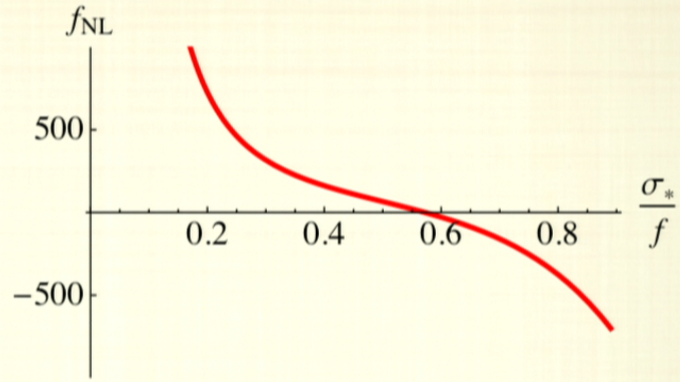




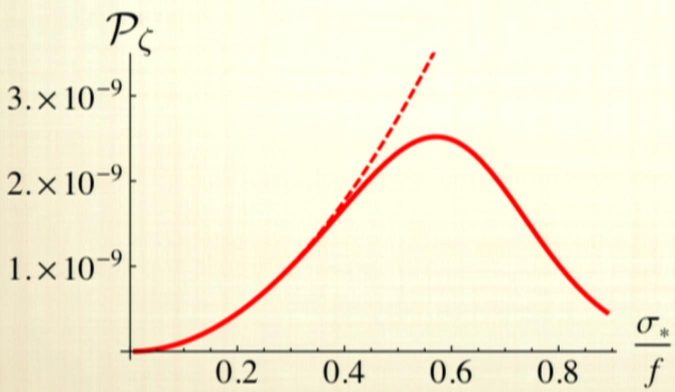
Self-Interacting Curvatons
V
−f
0
f
σ
fNL
500
−500
0.2
0.4
0.6
0.8
σ*/f
When varyin
suppression due to curvaton rolling
𝒫ζ
3.×10^−9
2.×10^−9
1.×10^−9
0.03
0.02
0.01
ρr
decay

Self-Interacting Curvatons

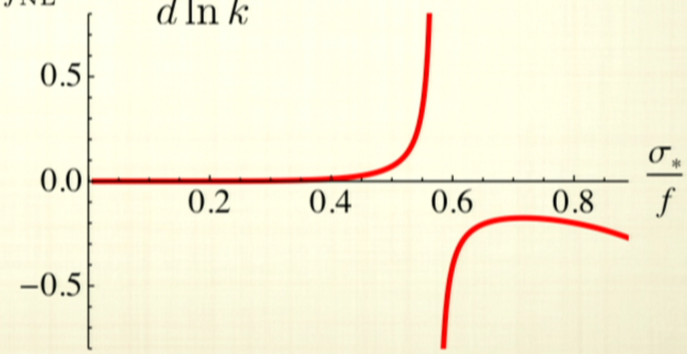




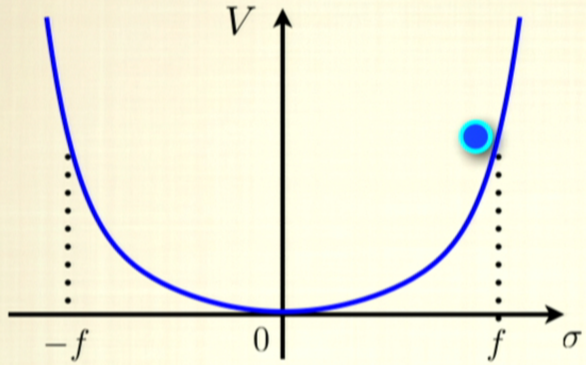
When varying σ_* :



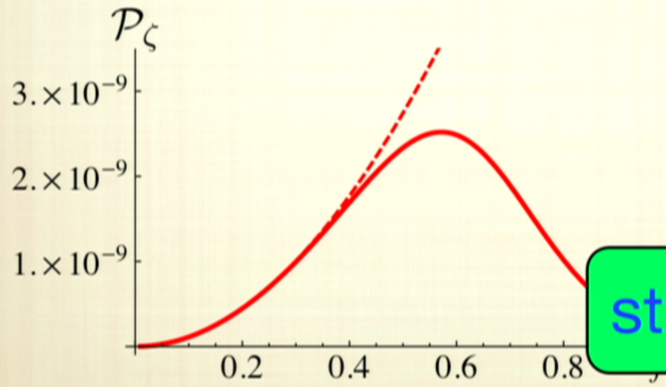
$$n_{f_{\rm NL}} = \frac{d \ln |f_{\rm NL}|}{d \ln k}$$

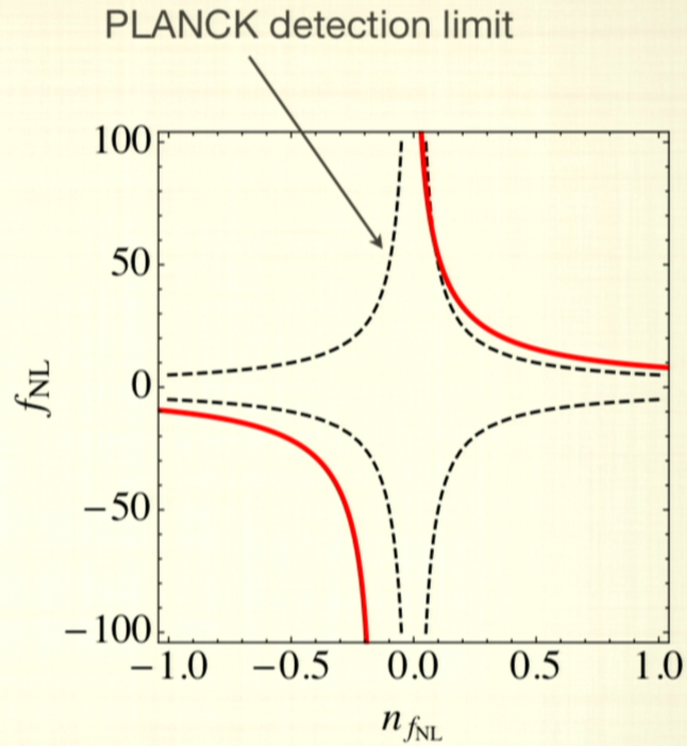


Self-Interacting Curvatons



When varying σ_* :





strongly scale-dependent f_{NL}

Summary of Non-Quad. Curvatons

- Non-quadratic curvatons exhibit new behaviors, such as inhomogenous onset of oscillations.

- Flat potentials enhanced density perturbations.

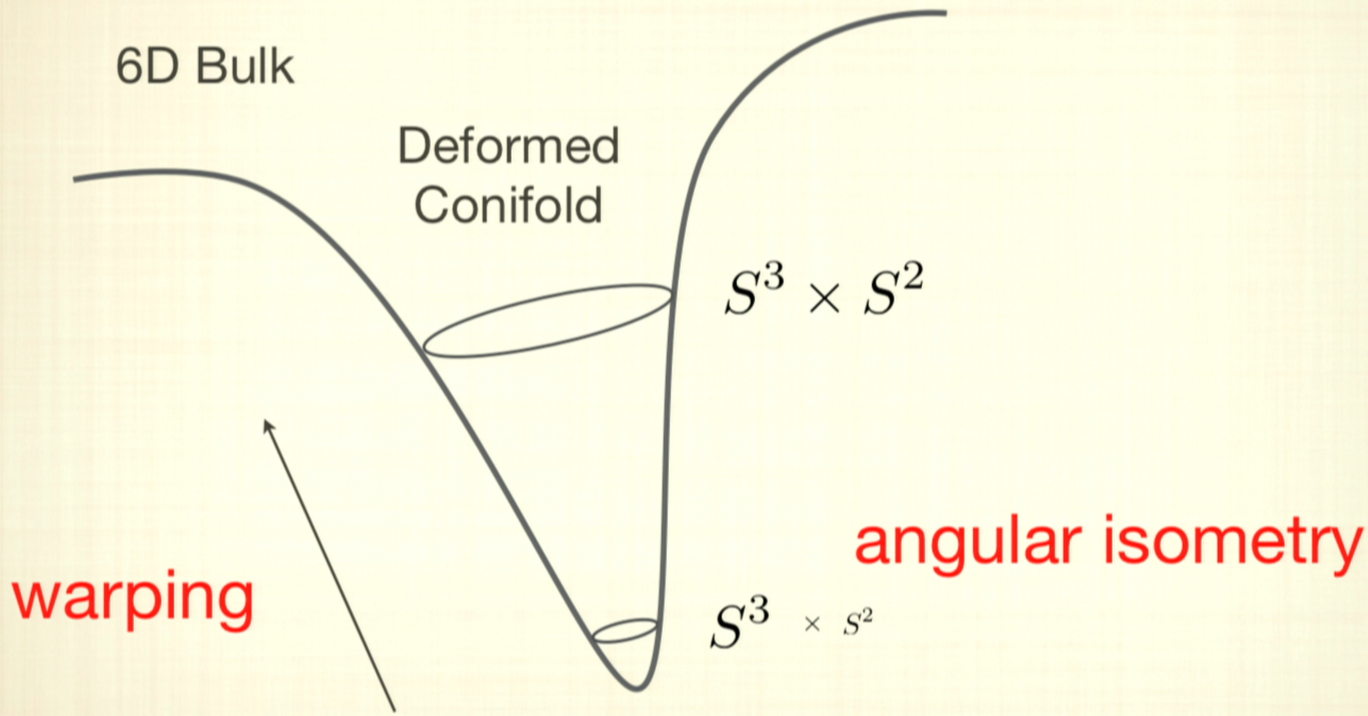
- Steep potentials can source strongly scale-dependent f_{NL}.

Curvatons in Warped Throats

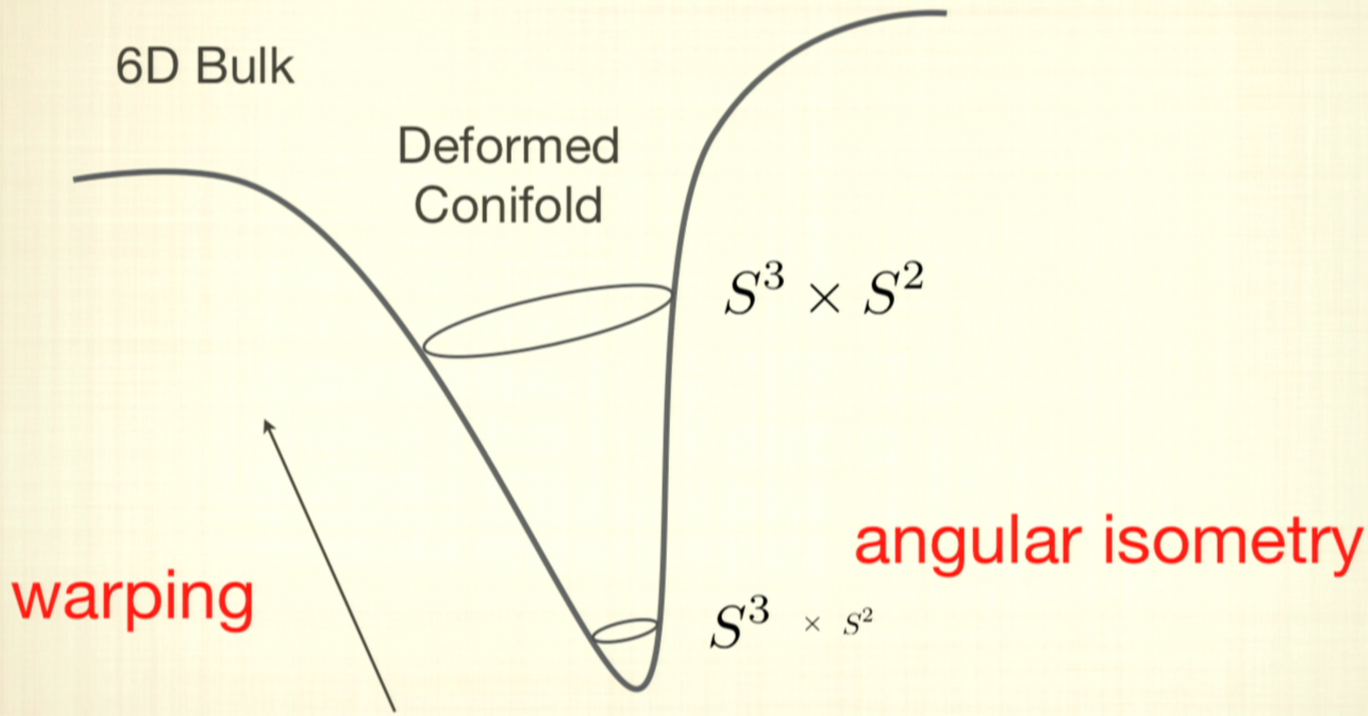
TK, Mukohyama '09

a curvaton scenario from type IIB string theory compactified on a warped throat with (approximate) isometries

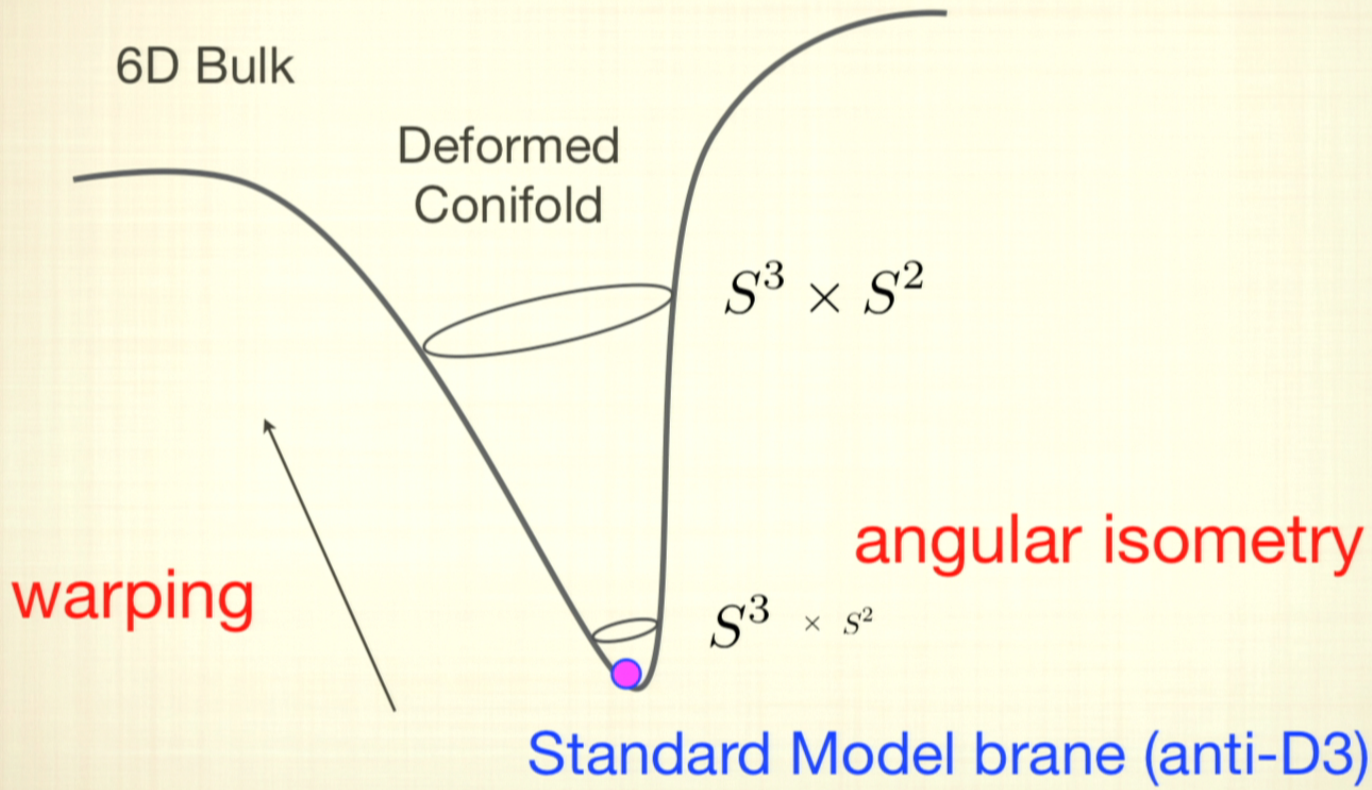
Curvatons in a Warped Throat



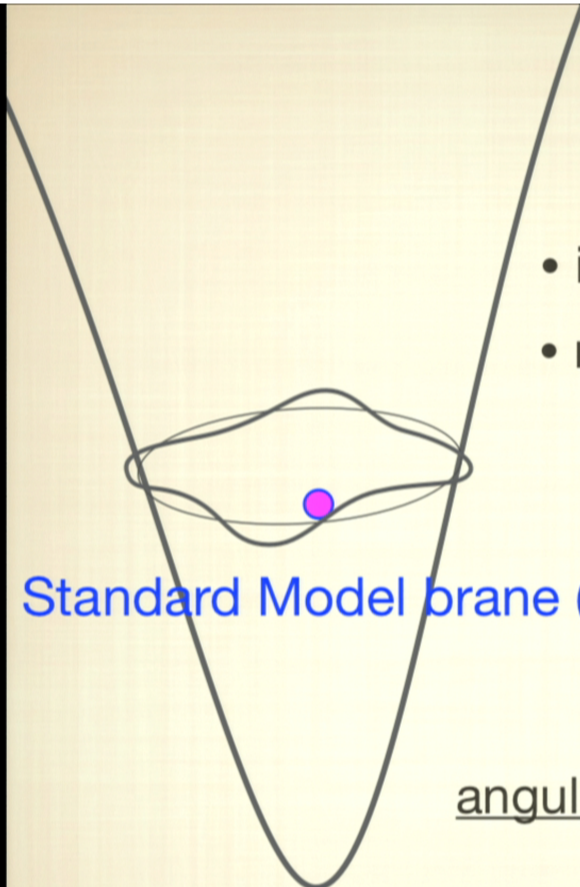
Curvatons in a Warped Throat



Curvatons in a Warped Throat



Angular Potential



- isometry breaking bulk effects
- moduli stabilizing non-perturbative effects

↓ + warping

small mass to the
<u>angular degrees of freedom</u> of the SM brane

II

CURVATON σ

→ eventually decays into other open string modes (reheating)

Action

$$S = -T_3 \int d^4\xi \sqrt{-\det G_{\mu\nu}}\,(1 - \bar{\Psi} i \not{D} \Psi) - T_3 \int C_4$$

$$\sim \int d^4x \sqrt{-g^{(4)}} \Big[-(\partial\sigma)^2 + \bar{\psi} i \not{D} \psi$$

$$- (m_{\rm bulk}^2 + m_{\rm np}^2)\sigma^2 + \frac{g_s M^{1/2} \alpha'^{3/2}}{h_0^3} \frac{m_{\rm bulk}^2 m_{\rm np}^2}{m_{\rm bulk}^2 + m_{\rm np}^2} \sigma \bar{\psi} i \not{D} \psi + \cdots \Big]$$

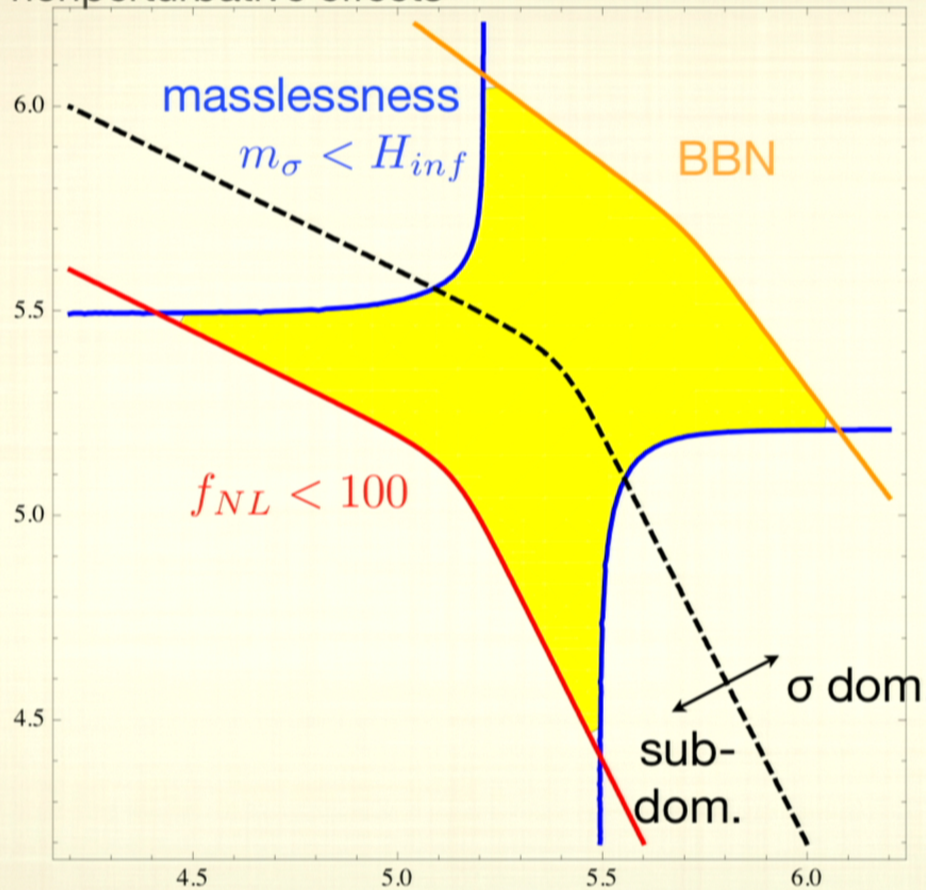
$$m_{\rm bulk}^2 = \frac{h_0^{\Delta-2}}{g_s M \alpha'}$$: bulk effects

$$m_{\rm np}^2 = \frac{h_0^{\lambda-2}}{g_s M \alpha'}$$: nonperturbative effects

h_0 : warp factor at the tip $\left(ds^2 = h^2 g_{\mu\nu}^{(4)} dx^\mu dx^\nu + h^{-2} g_{mn}^{(6)} dx^m dx^n \right)$

Parameter Constraints

λ : nonperturbative effects



$g_s = 0.1$

$M_{pl}\alpha'^{1/2} = 300$

$h_0 = 10^{-5}$

$N = 50000$

(hence $H_{inf} \sim 10^{-11} f_{\rm NL} M_{pl}$)

Δ : bulk effects

Action

$$S = -T_3 \int d^4\xi \sqrt{-\det G_{\mu\nu}}\,(1 - \bar{\Psi} i \not{D} \Psi) - T_3 \int C_4$$

$$\sim \int d^4x \sqrt{-g^{(4)}} \Big[-(\partial\sigma)^2 + \bar{\psi} i \not{D} \psi$$

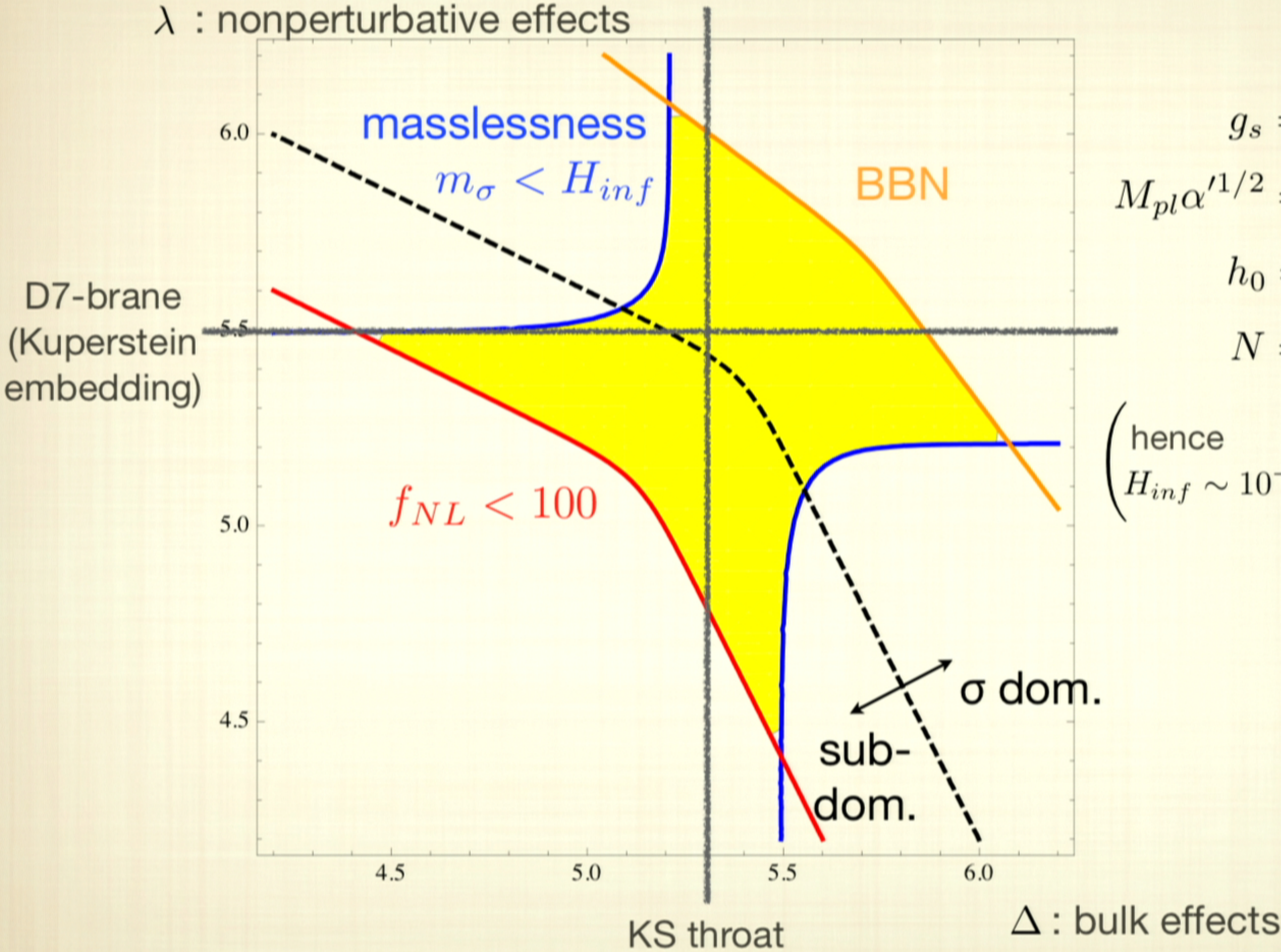
$$- (m_{\rm bulk}^2 + m_{\rm np}^2)\sigma^2 + \frac{g_s M^{1/2} \alpha'^{3/2}}{h_0^3} \frac{m_{\rm bulk}^2 m_{\rm np}^2}{m_{\rm bulk}^2 + m_{\rm np}^2} \sigma \bar{\psi} i \not{D} \psi + \cdots \Big]$$

$$m_{\rm bulk}^2 = \frac{h_0^{\Delta - 2}}{g_s M \alpha'}$$: bulk effects

$$m_{\rm np}^2 = \frac{h_0^{\lambda - 2}}{g_s M \alpha'}$$: nonperturbative effects

h_0 : warp factor at the tip $\left(ds^2 = h^2 g_{\mu\nu}^{(4)} dx^\mu dx^\nu + h^{-2} g_{mn}^{(6)} dx^m dx^n \right)$

Parameter Constraints



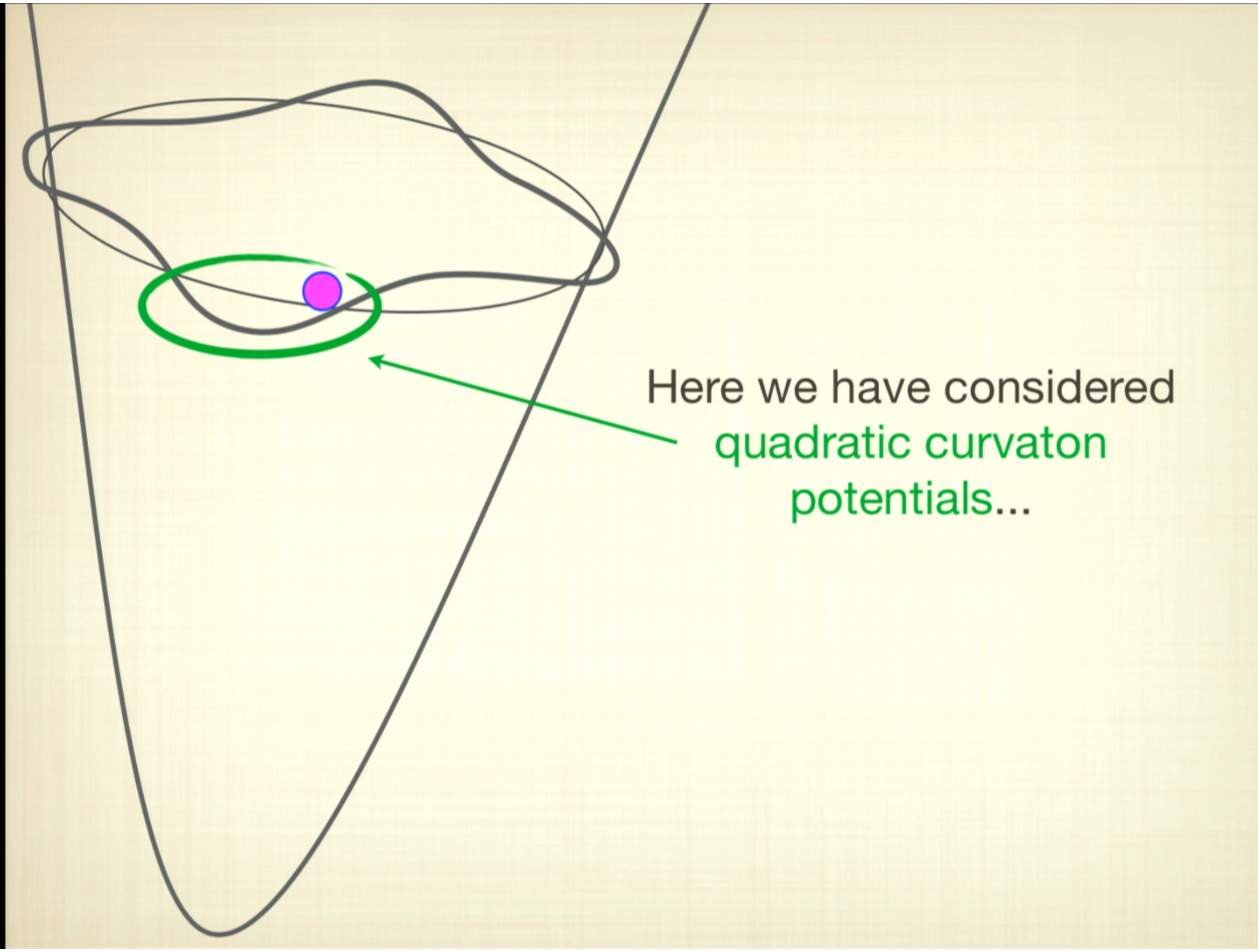
$g_s = 0.1$

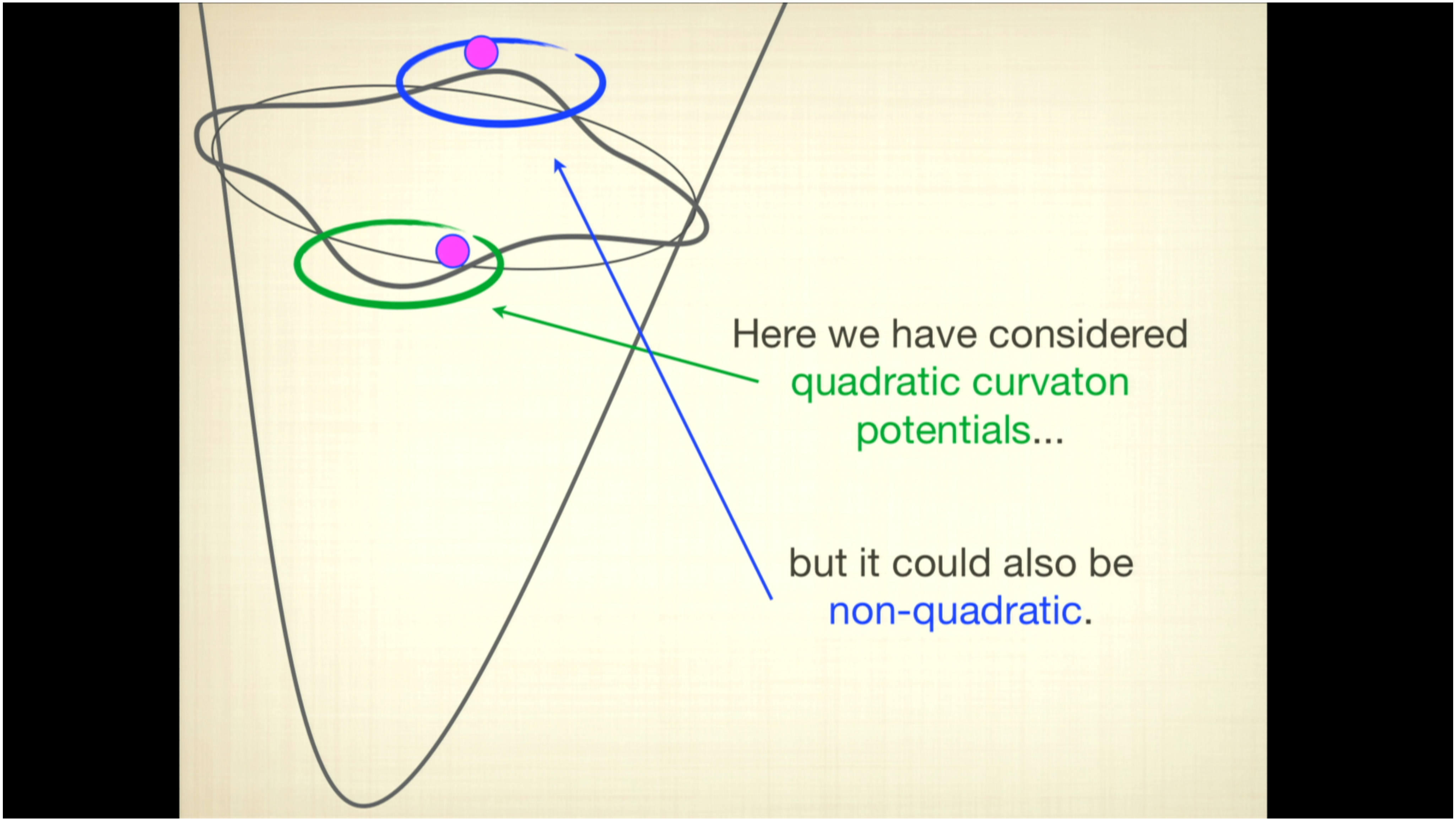
$M_{pl}\alpha'^{1/2} = 300$

$h_0 = 10^{-5}$

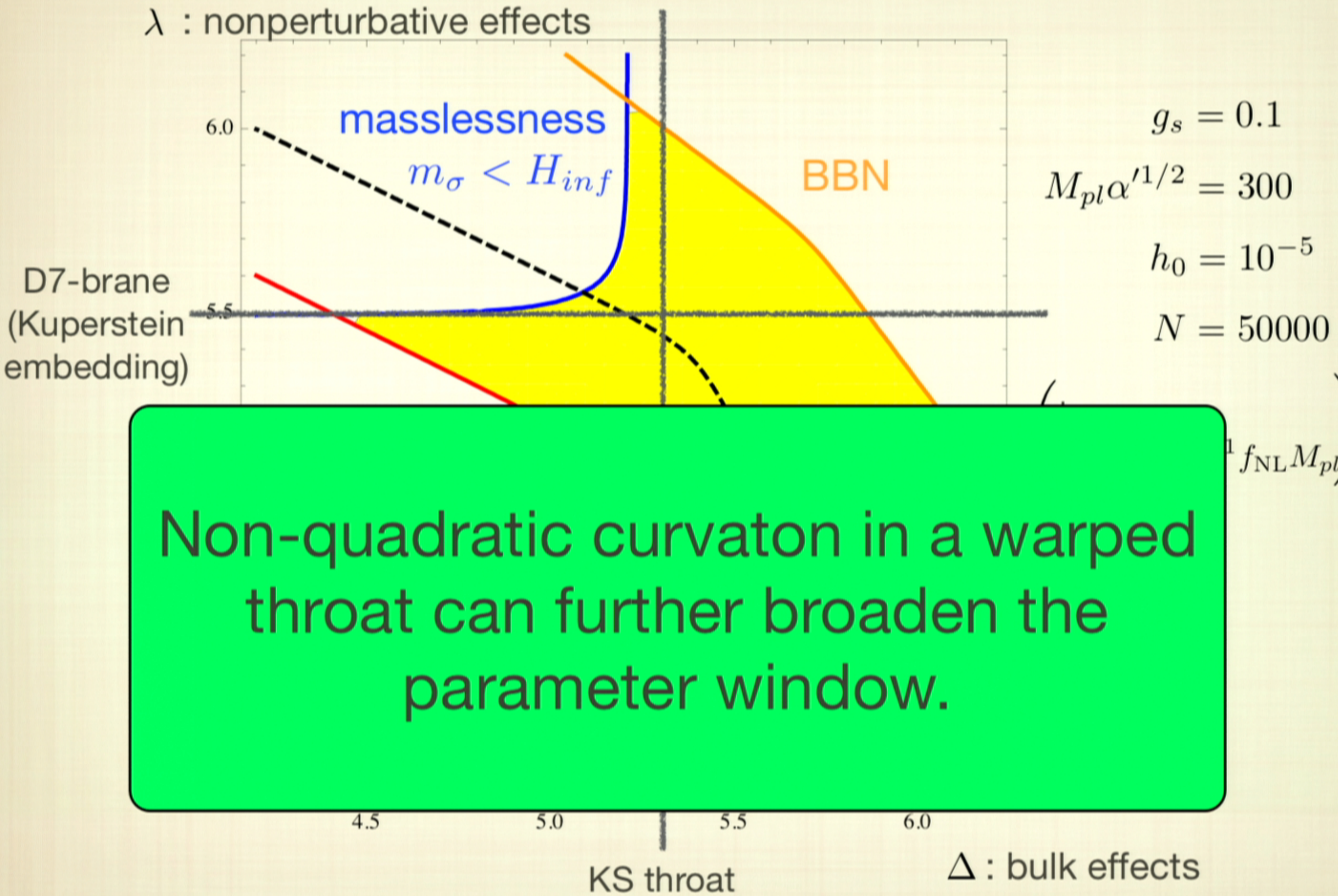
$N = 50000$

(hence $H_{inf} \sim 10^{-11} f_{\rm NL} M_{pl}$)


Here we have considered
quadratic curvaton
potentials...

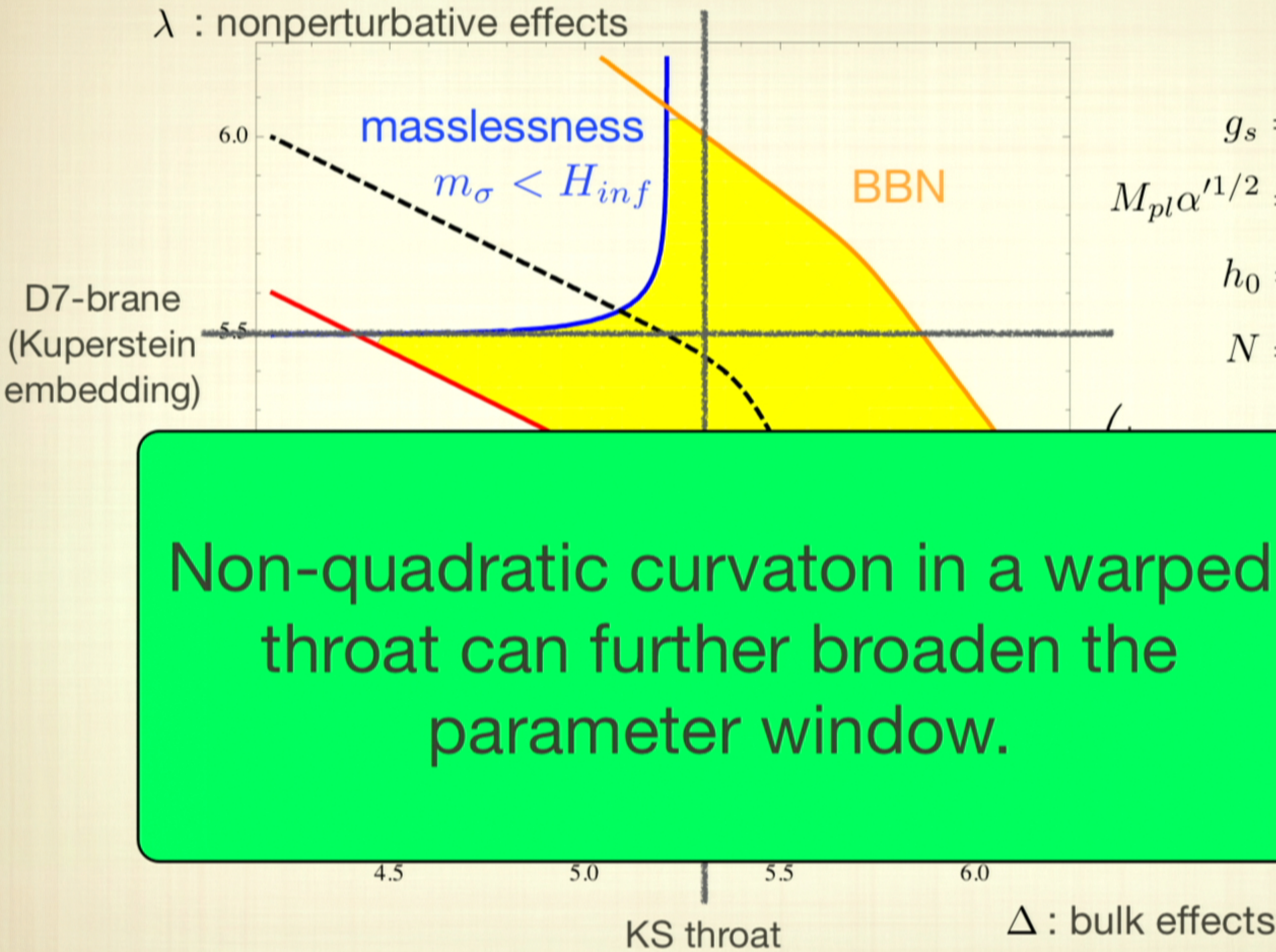

Here we have considered
quadratic curvaton
potentials...
but it could also be
non-quadratic.

Parameter Constraints



Non-quadratic curvaton in a warped throat can further broaden the parameter window.

Parameter Constraints



$g_s = 0.1$

$M_{pl}\alpha'^{1/2} = 300$

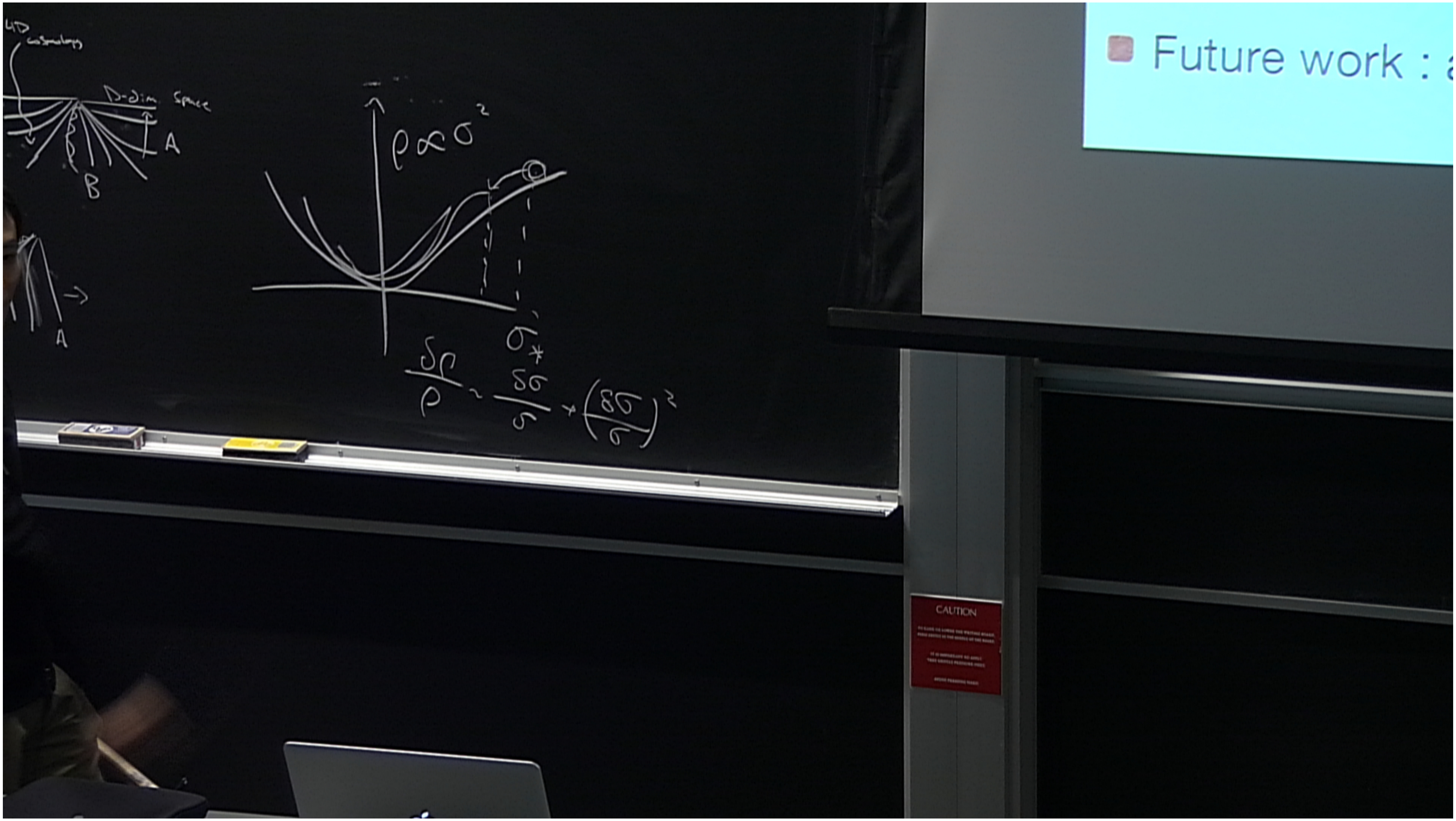
$h_0 = 10^{-5}$

$N = 50000$

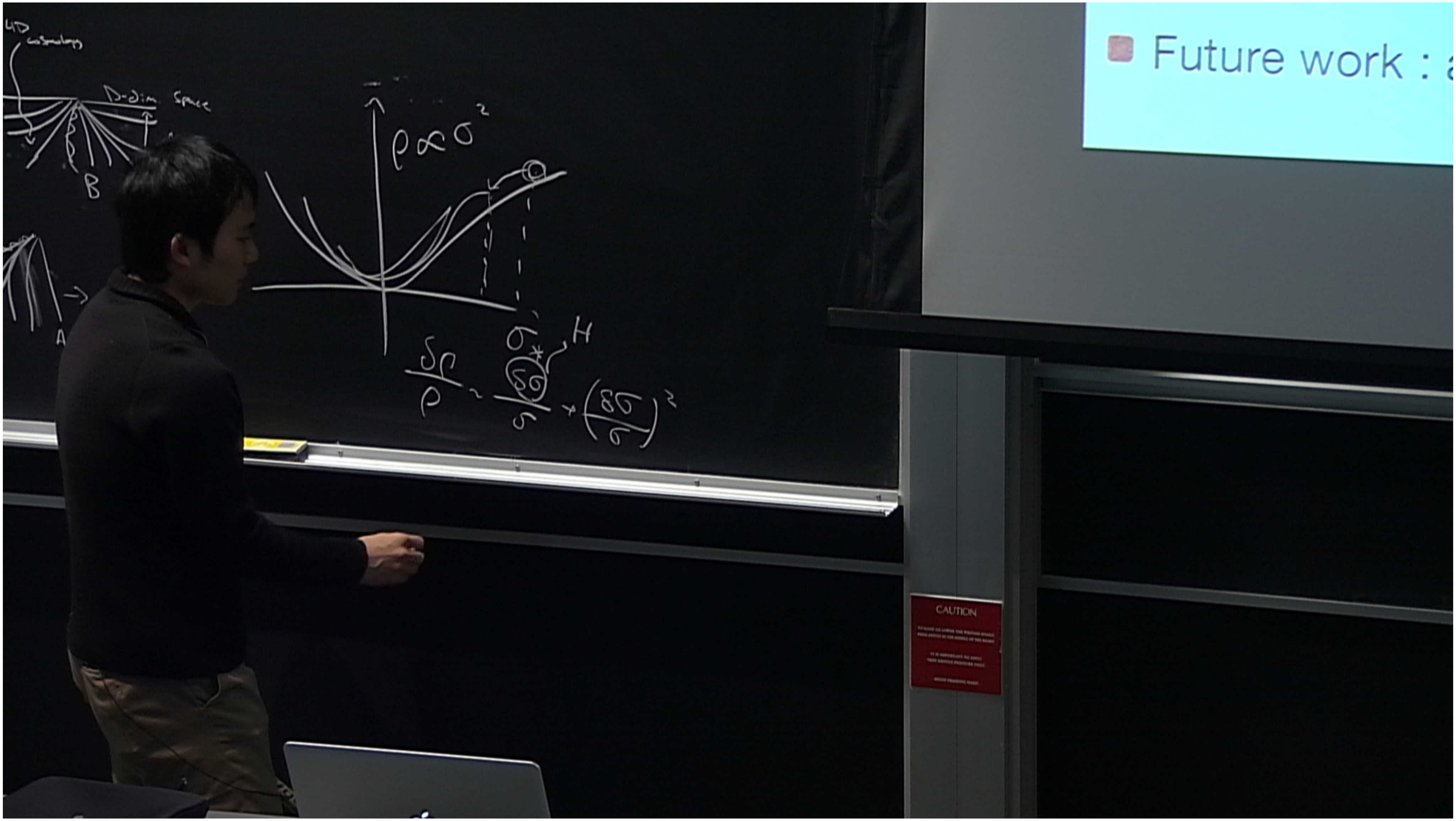
Non-quadratic curvaton in a warped throat can further broaden the parameter window.

Summary

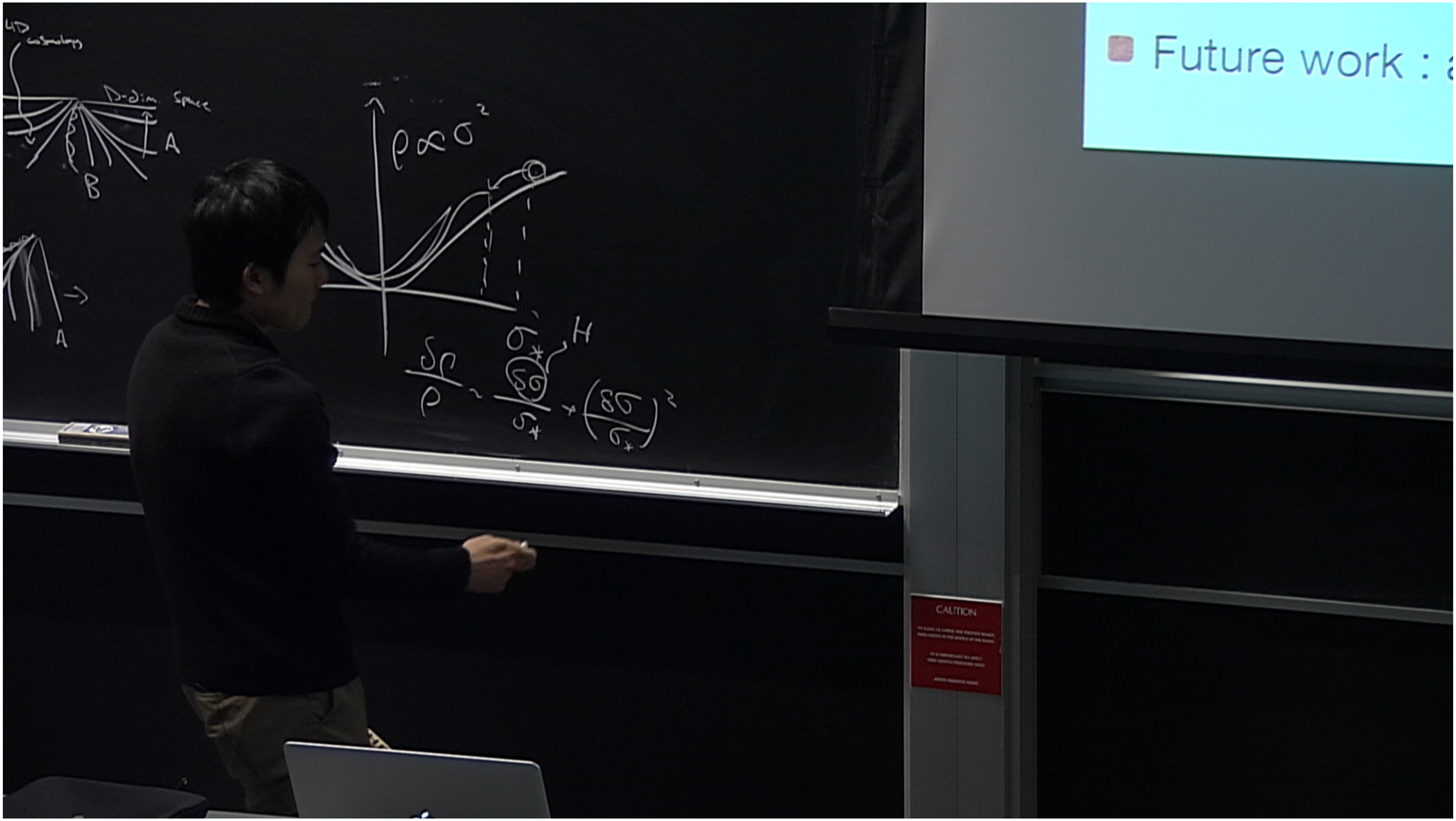
- We analytically investigated density perturbations from a curvaton with a generic energy potential.
- Rich phenomenology : Flattened (compared to a quadratic) potentials can enhance linear & second order perturbations (large f_{NL} even for dominant curvatons!), steepened potentials can source running f_{NL}, and more.
- Curvatons can be realized by angular motions of D-branes in warped throats.
- Future work : applications to microscopic models.



4D cosmology
D-dim Space
A
B
A
$\rho \propto \sigma^2$
σ_*
$\frac{\delta\rho}{\rho} \sim \frac{\delta\sigma}{\sigma} + \left(\frac{\delta\sigma}{\sigma}\right)^2$
Future work :
CAUTION



D-dim. Space
B
A
$\rho \propto \sigma^2$
H
$\frac{\delta\rho}{\rho} \sim \frac{\delta\sigma}{\sigma} + \left(\frac{\delta\sigma}{\sigma}\right)^2$
Future work : a
CAUTION


Future work : a
CAUTION