Density Perturbations from Curvatons Revisited

Takeshi Kobayashi (CITA)

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

PASCOS 2012

The Curvaton Paradigm

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

generates cosmological perturbations from field fluctuations of a “curvaton” field

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however...

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

Why Consider Non-Quadratic Curvatons?

- microscopic realizations can give complicated energy potentials

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

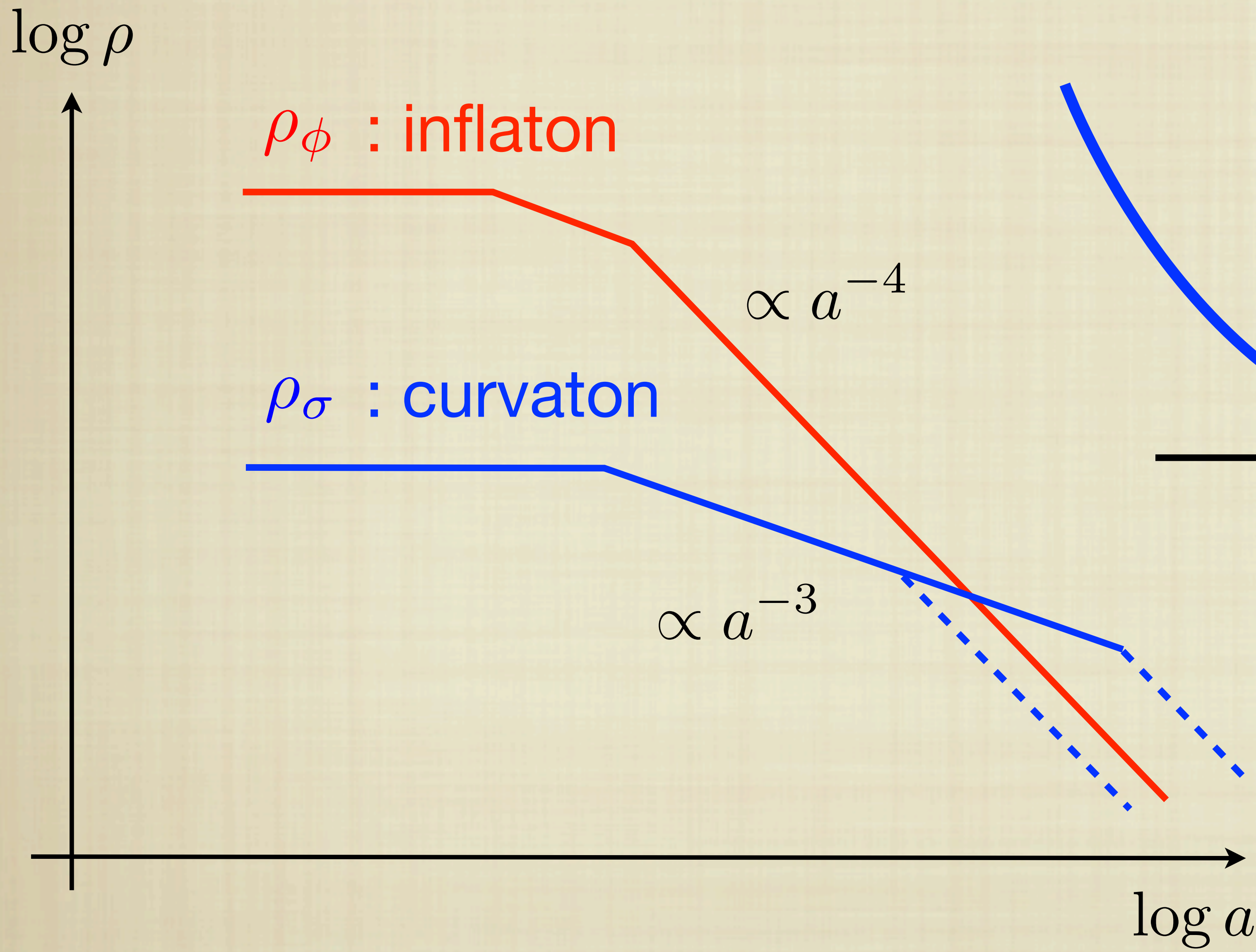
$$n_s - 1 = \frac{2}{3}\frac{V''}{H^2} + 2\frac{\dot{H}}{H^2} = -0.032 \pm 0.012 \quad \text{(WMAP7, 68\%CL)}$$

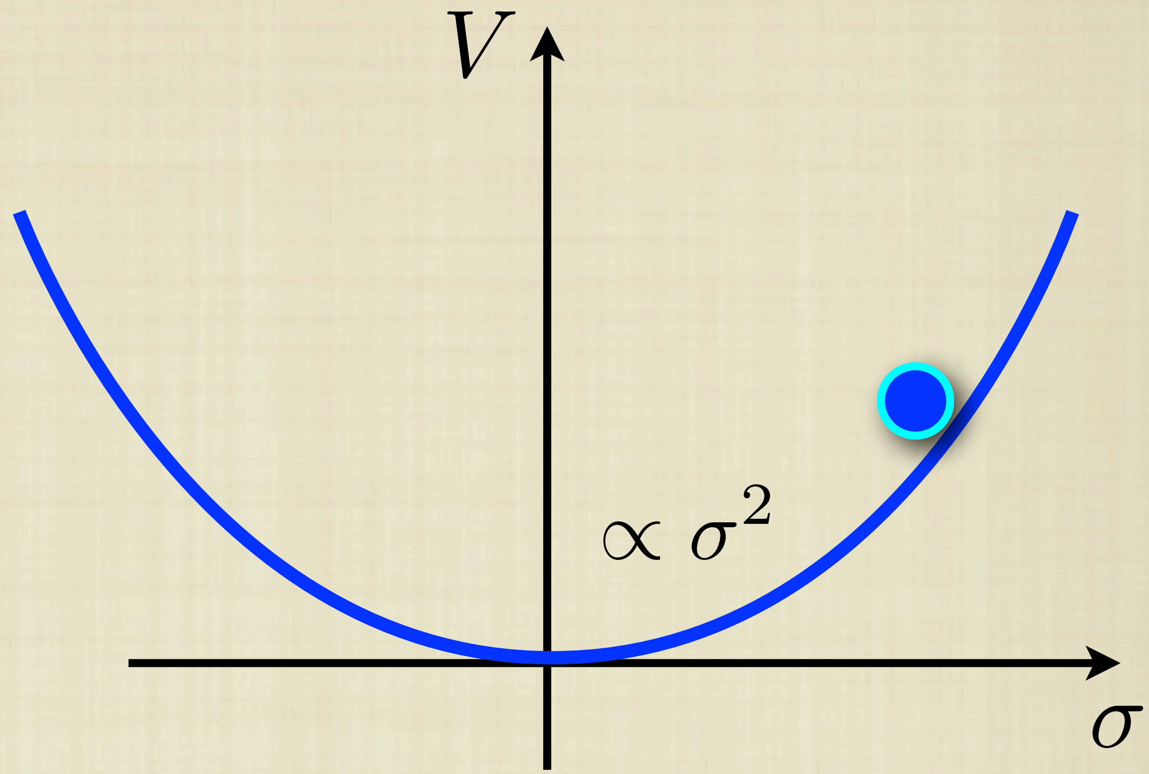
This Work :
Curvatons with Generic Potentials

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

The Quadratic Curvaton Scenario

: a light field with negligible energy density during inflation





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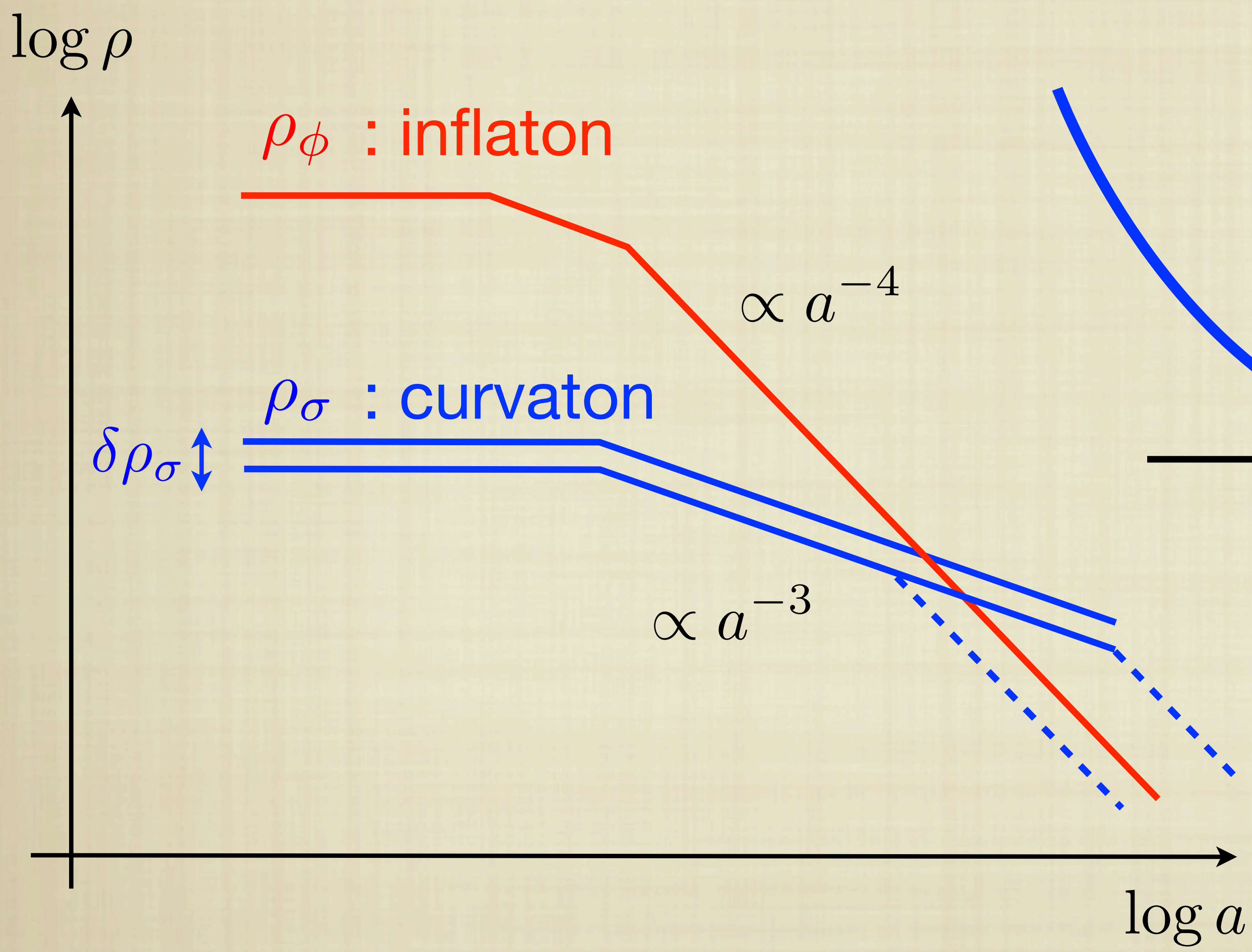

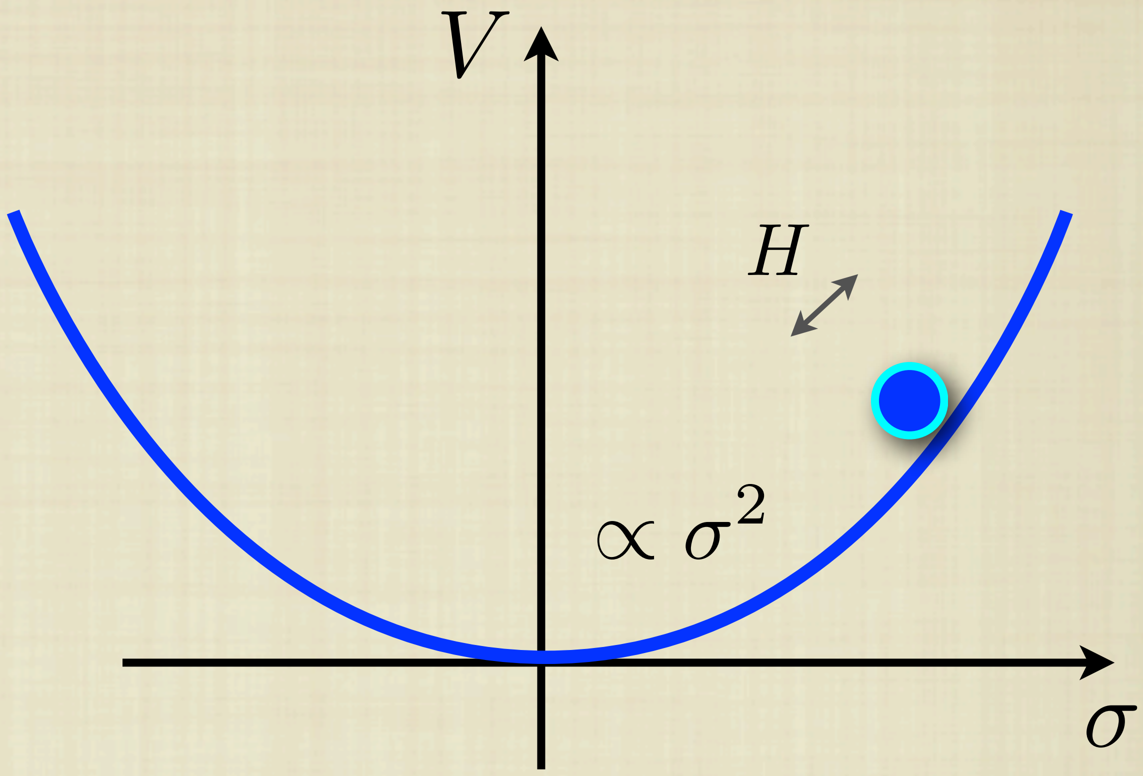

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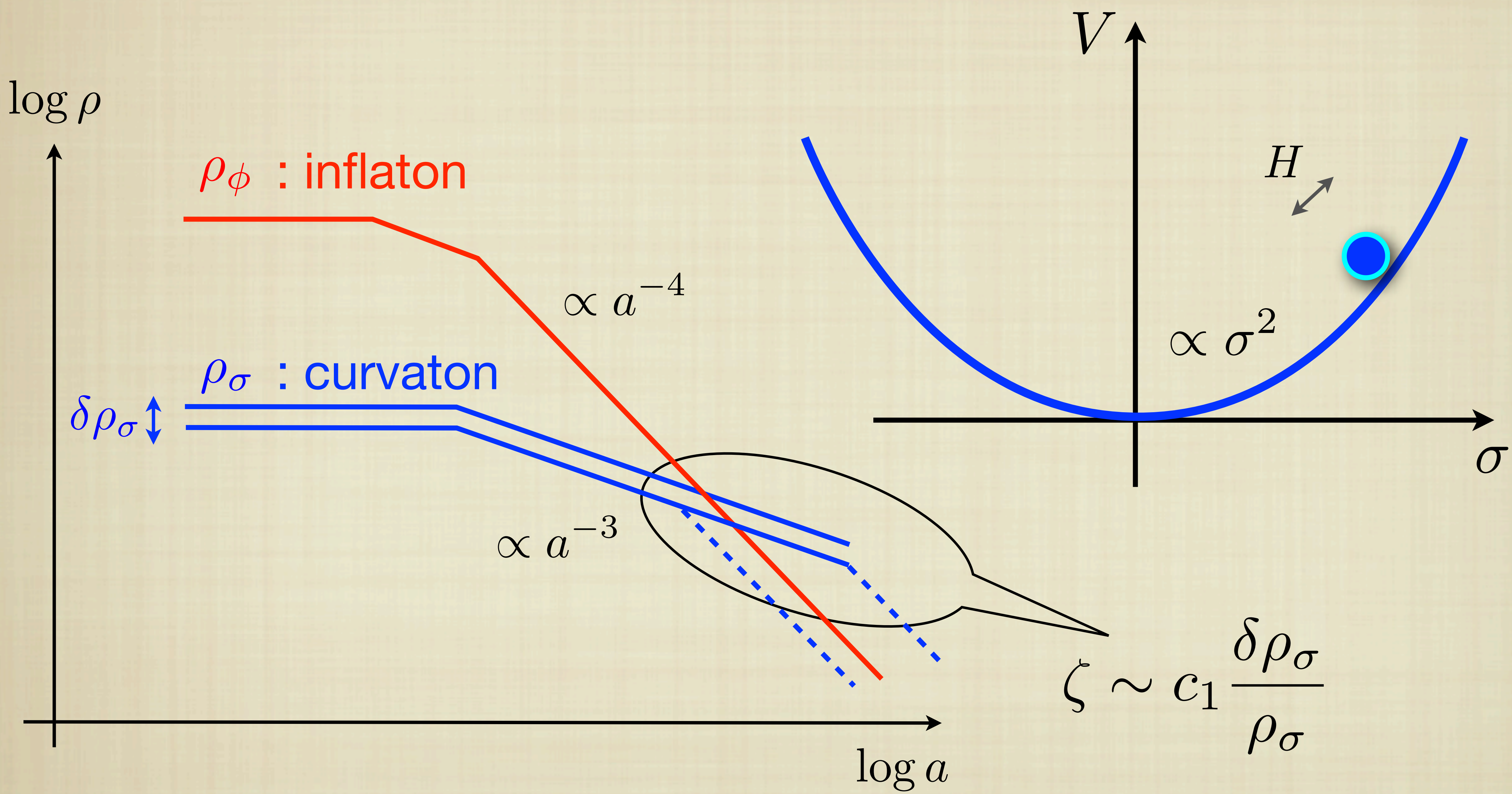
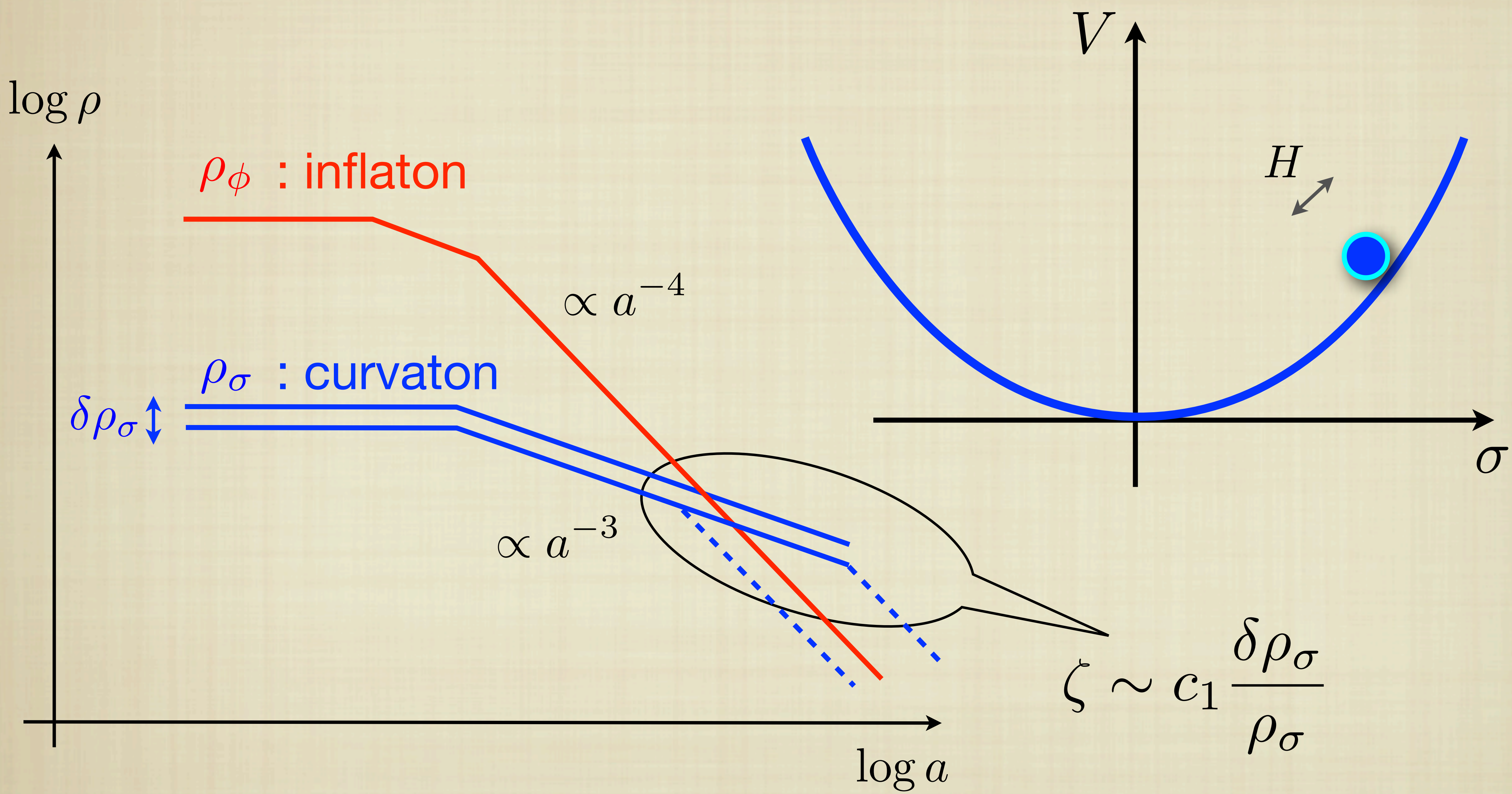


Curvatons with Arbitrary Potentials



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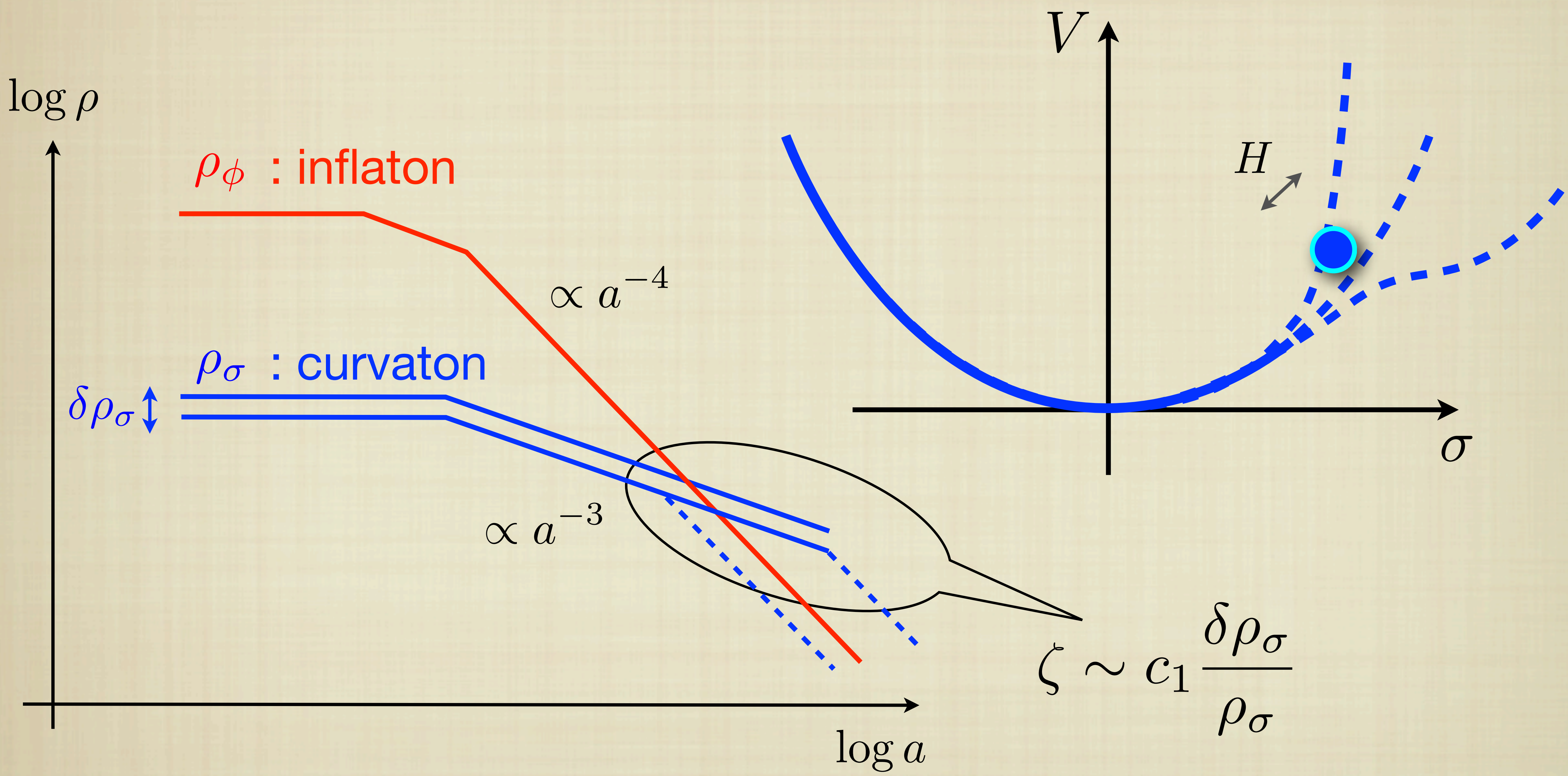
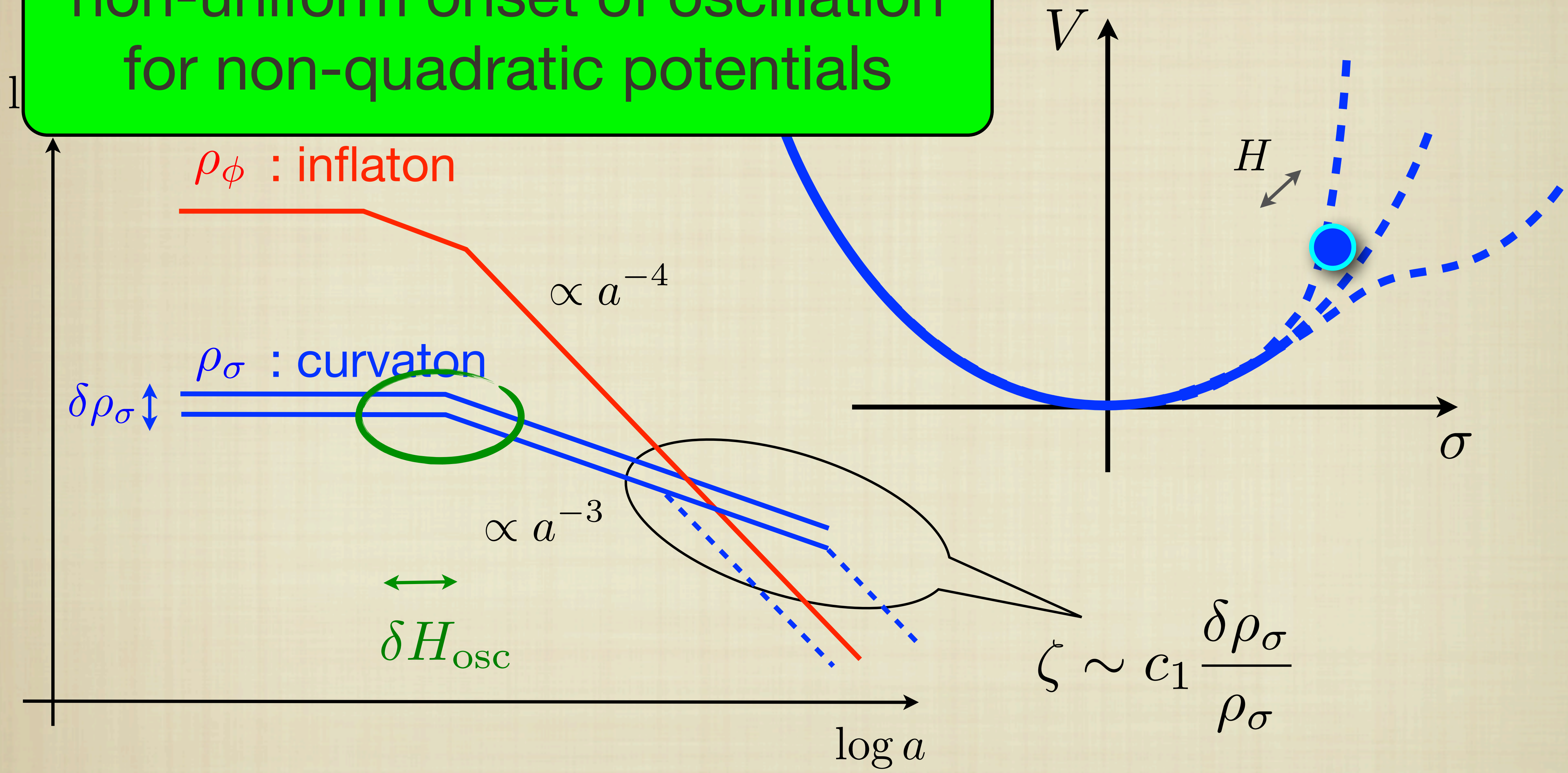


Curvatons with Arbitrary Potentials

non-uniform onset of oscillation
for non-quadratic potentials



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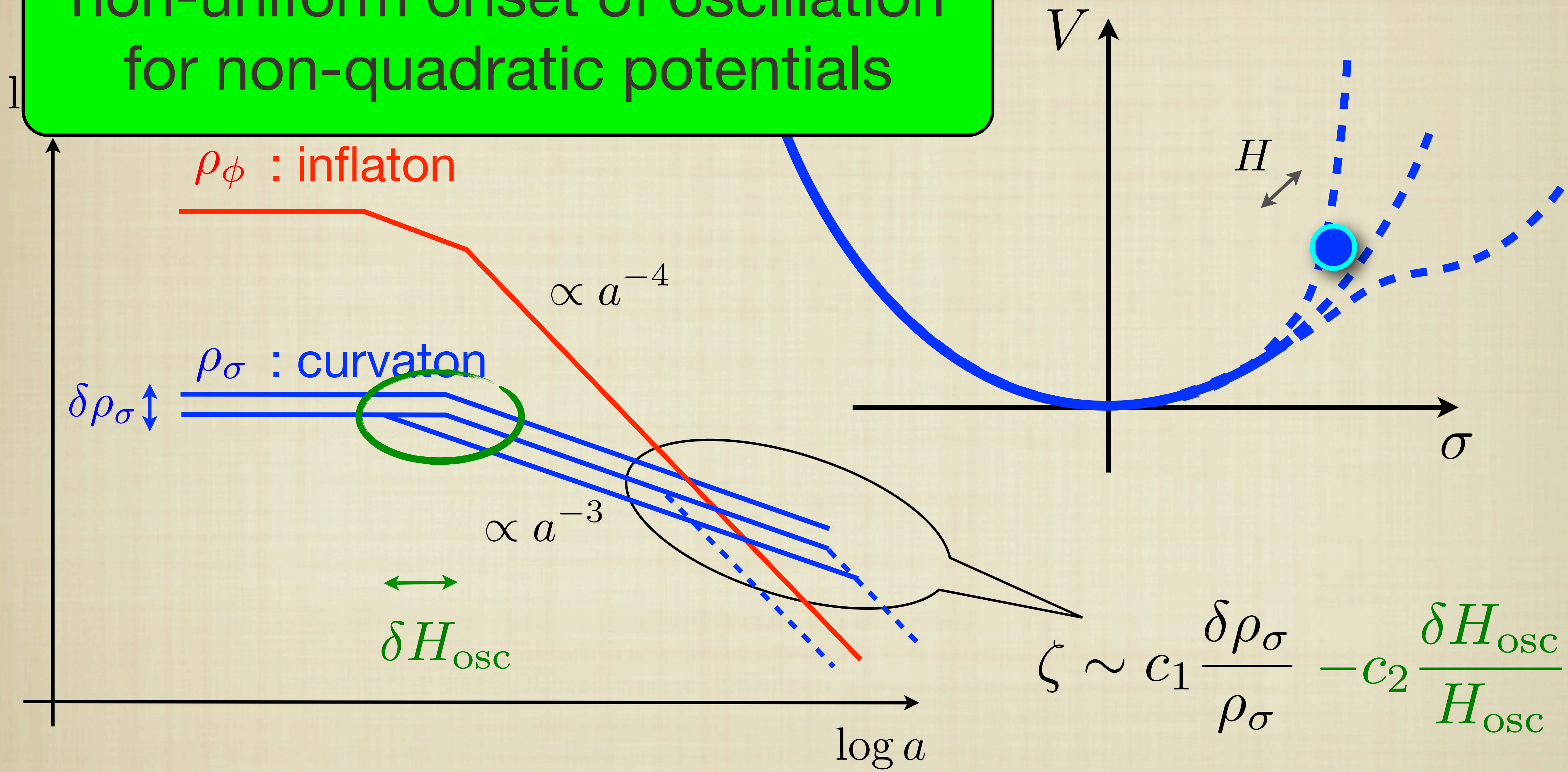

$$\zeta \sim c_1 \frac{\delta\rho_\sigma}{\rho_\sigma} - c_2 \frac{\delta H_{\rm osc}}{H_{\rm osc}}$$

Additional contributions to the density perturbations!

Density Perturbations

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

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

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

$*$: @ horizon exit

osc : @ onset of curvaton oscillation

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

: effects due to non-uniform onset of oscillation

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

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

Non-Gaussianity

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

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

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

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cf. quadratic curvatons : $f_{\rm NL} \sim \dfrac{1}{r}$

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

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

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

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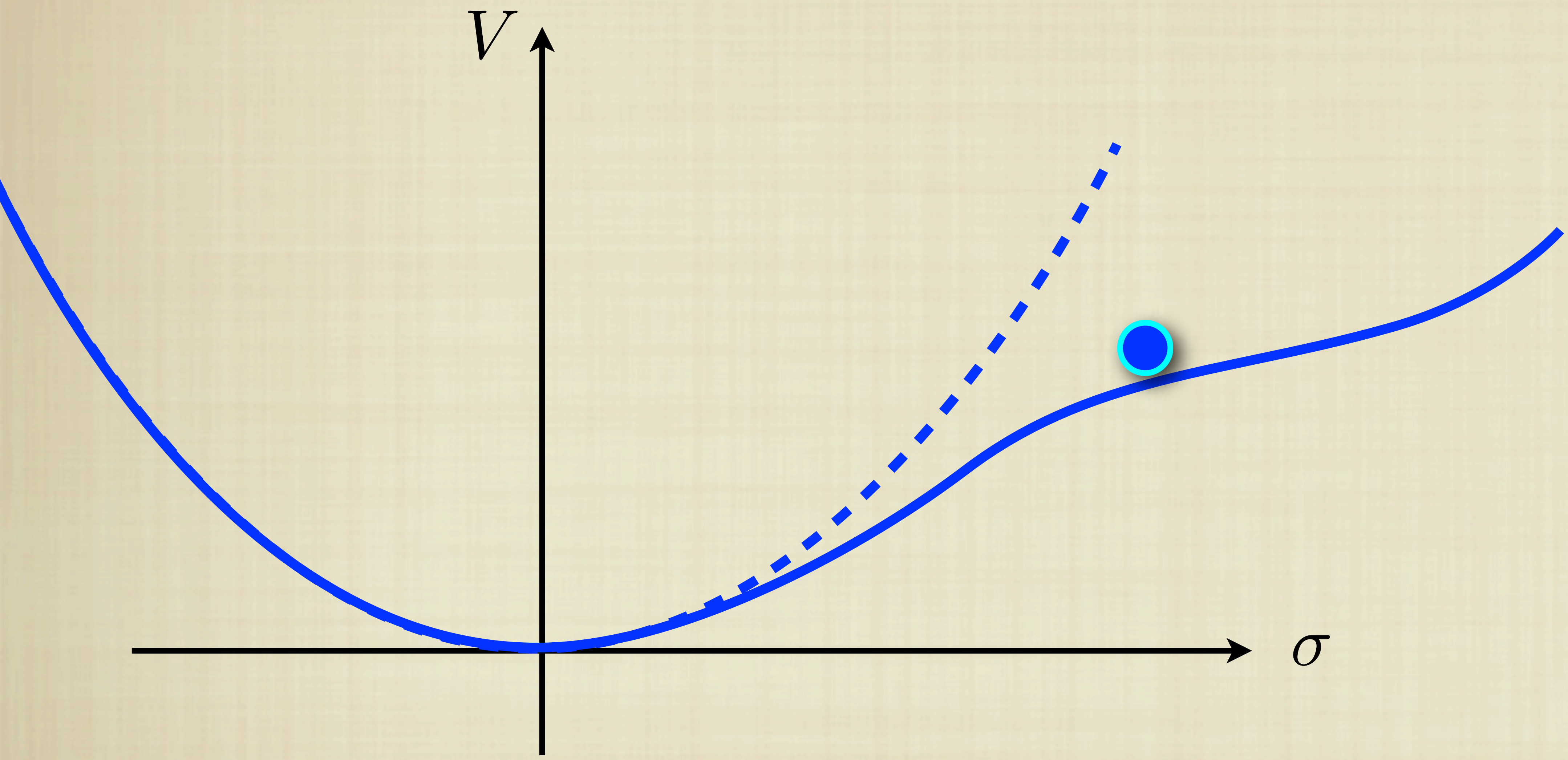
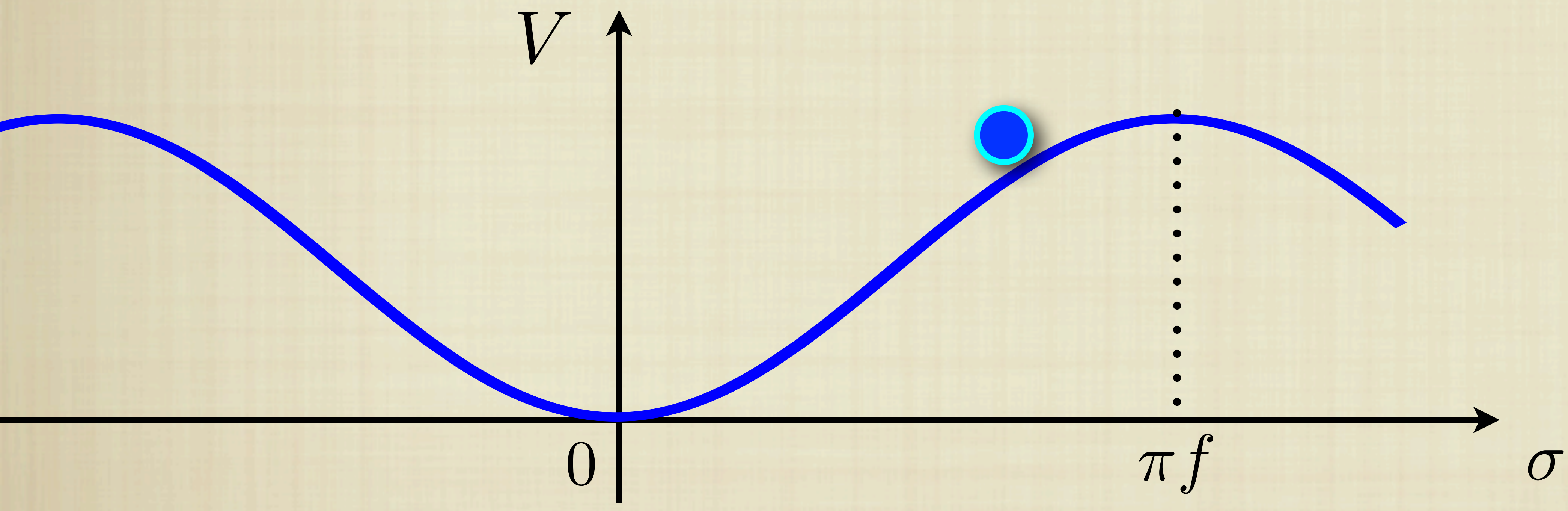
1. Flat Potentials



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

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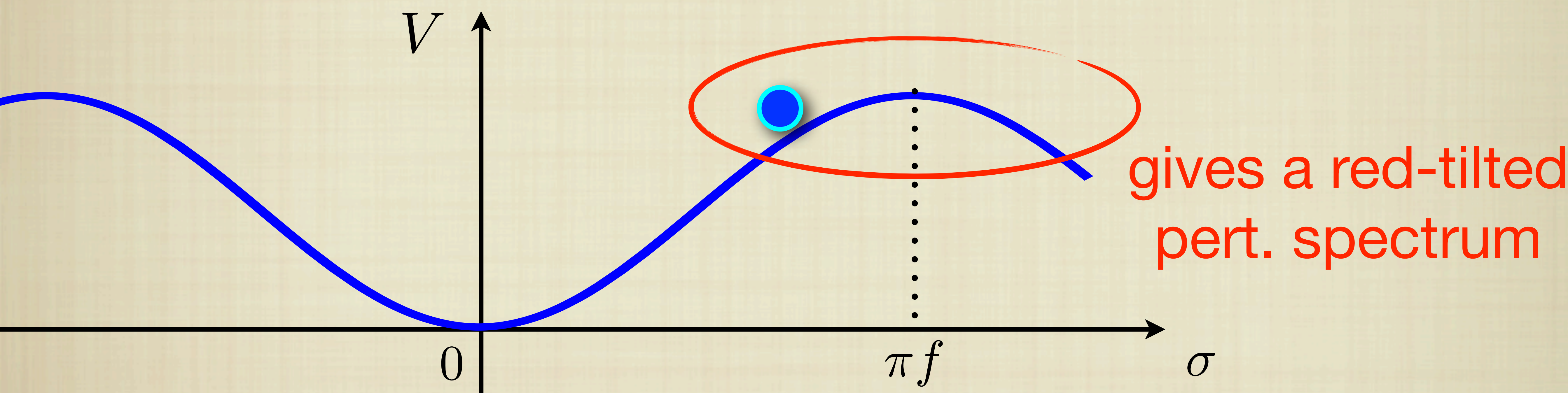

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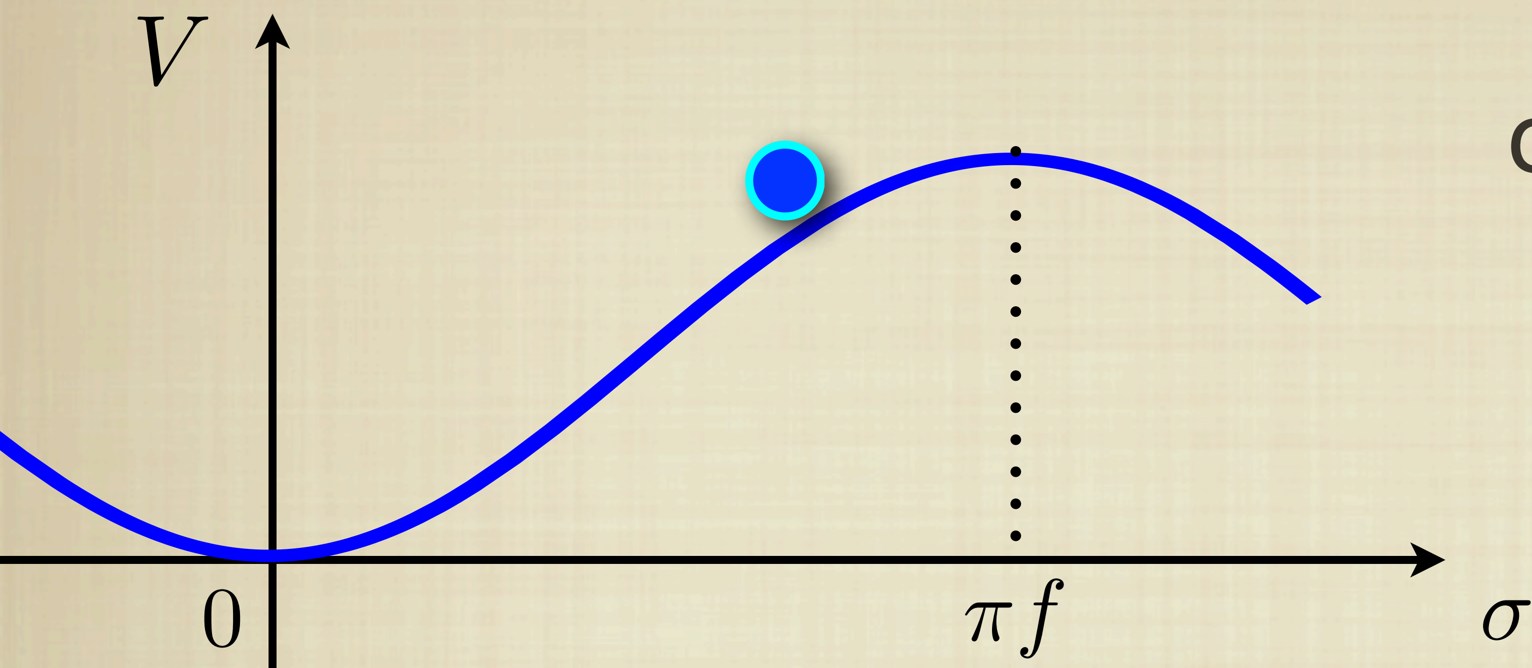
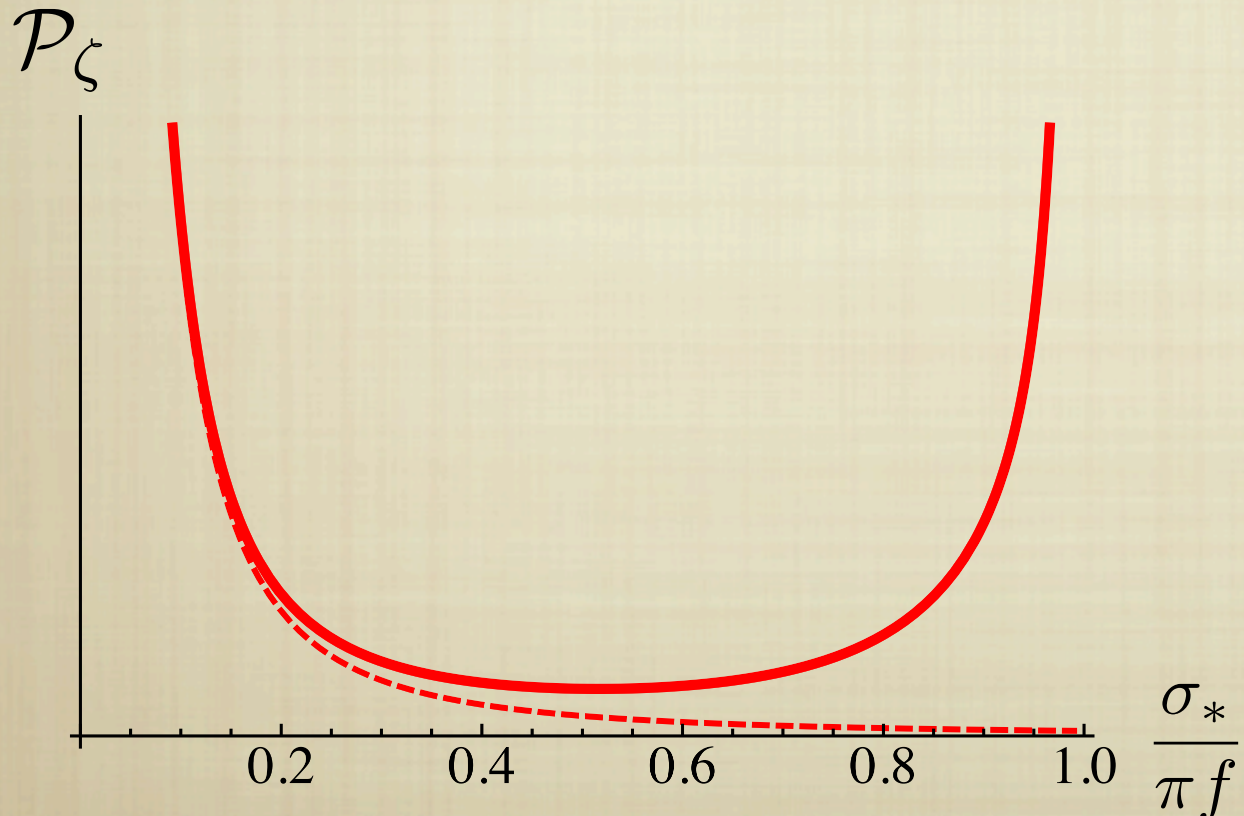
Density Pert. from a NG-Curvaton

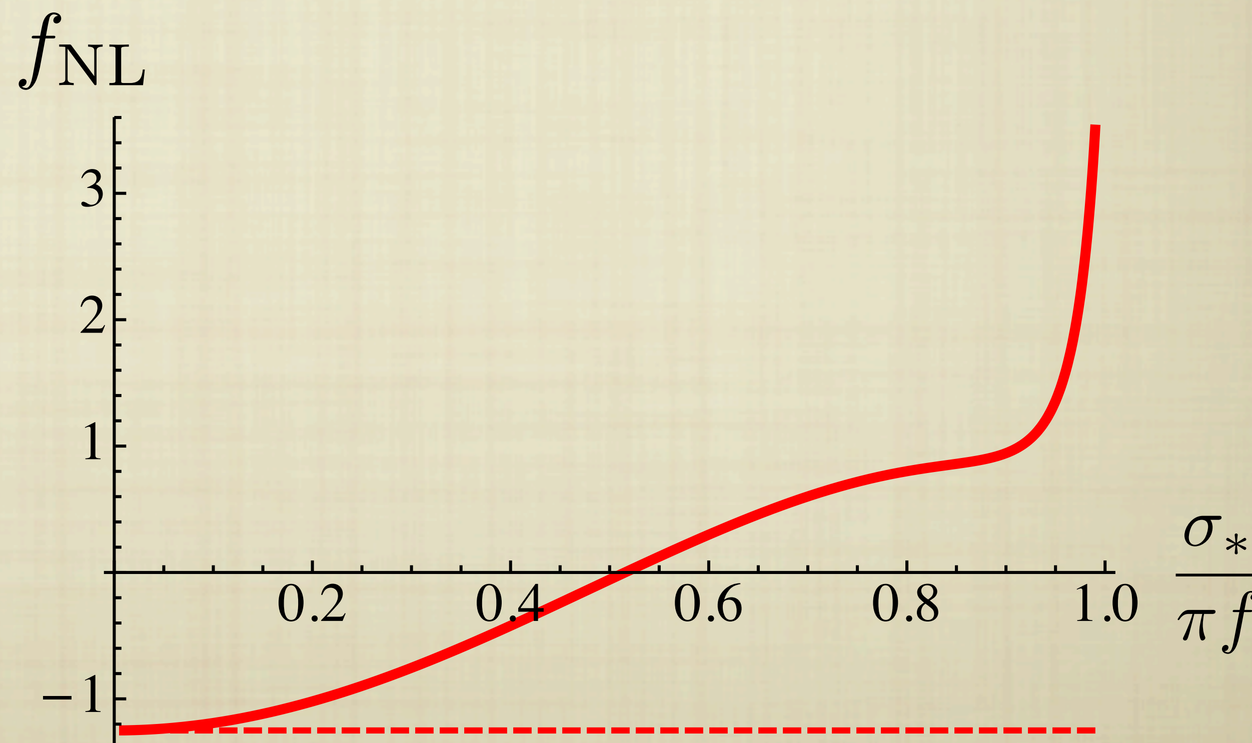


curvaton dominant case,

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

When varying σ_* :





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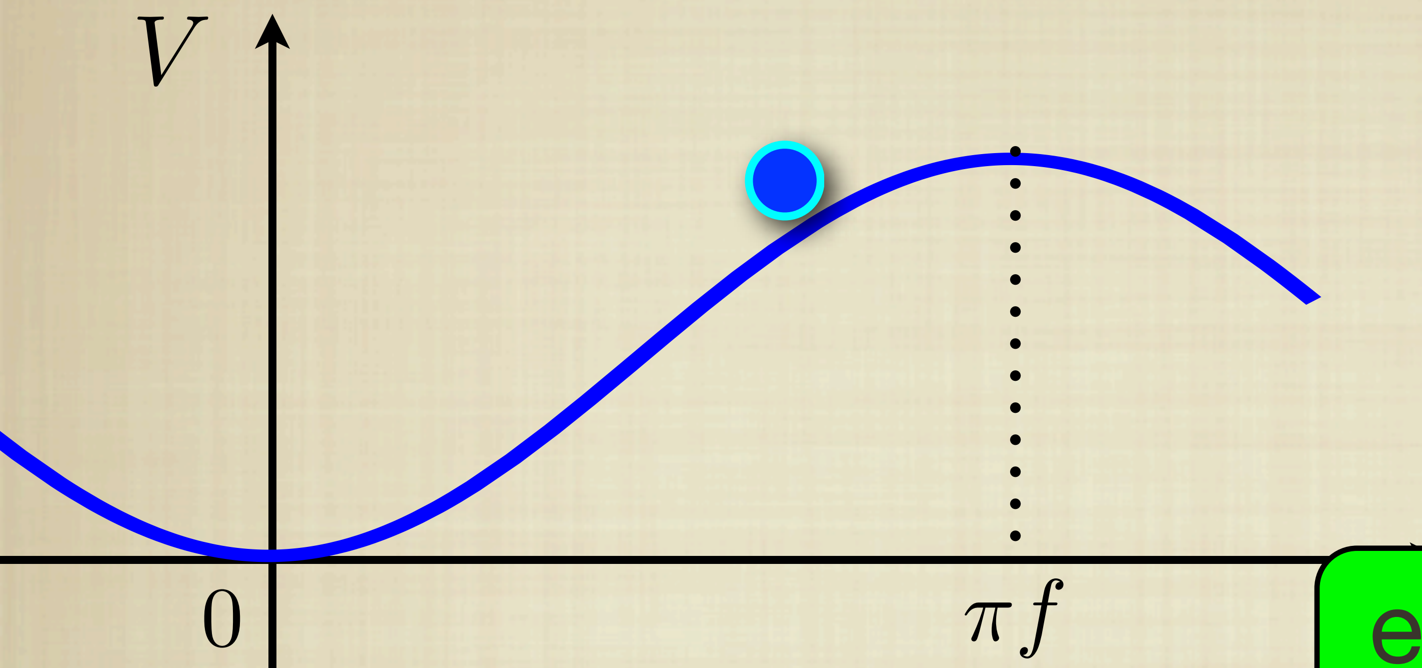

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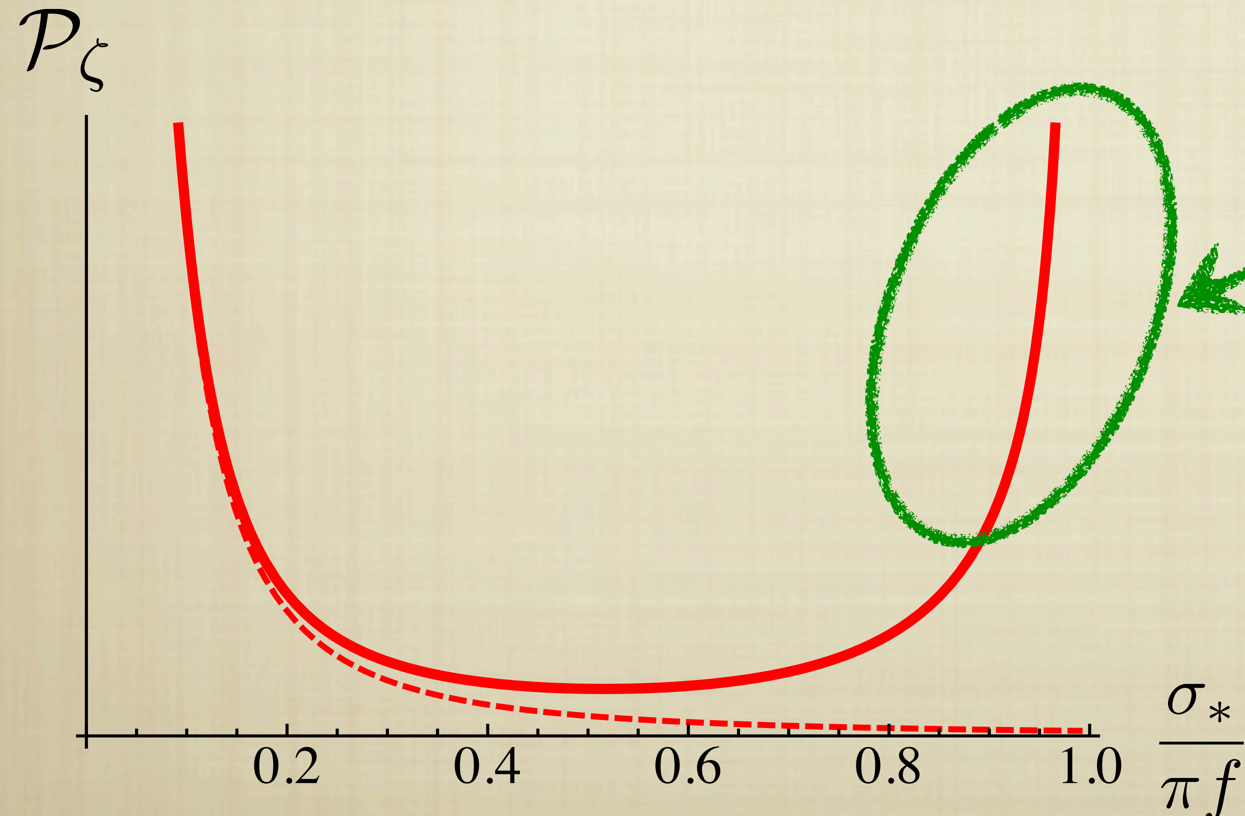
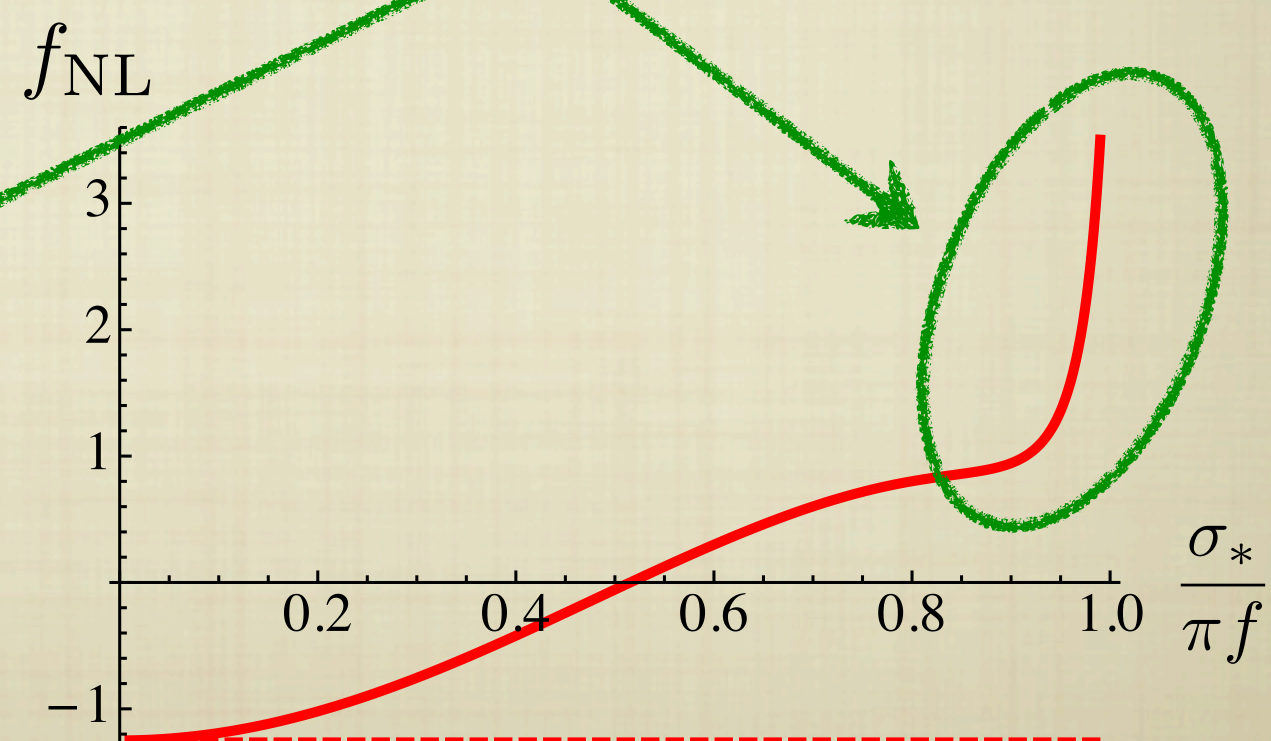
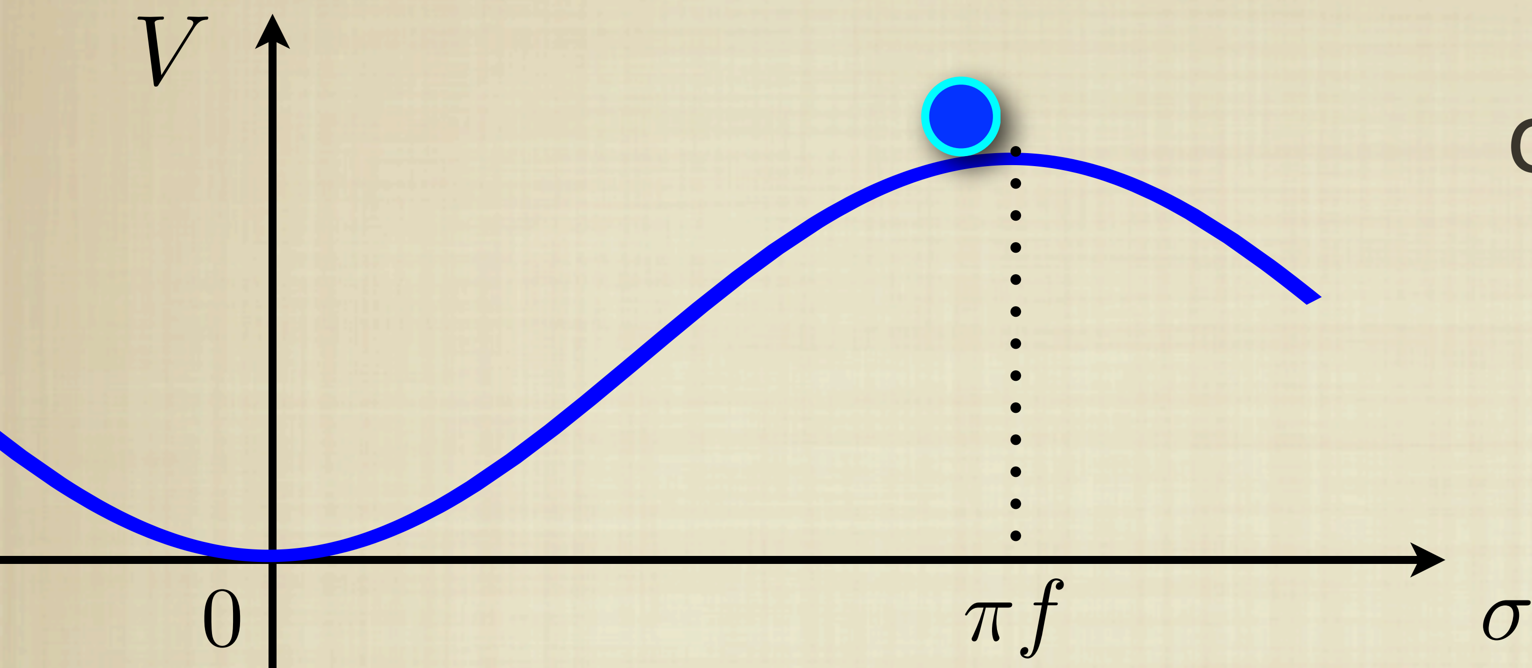




Density Pert. from the Hilltop



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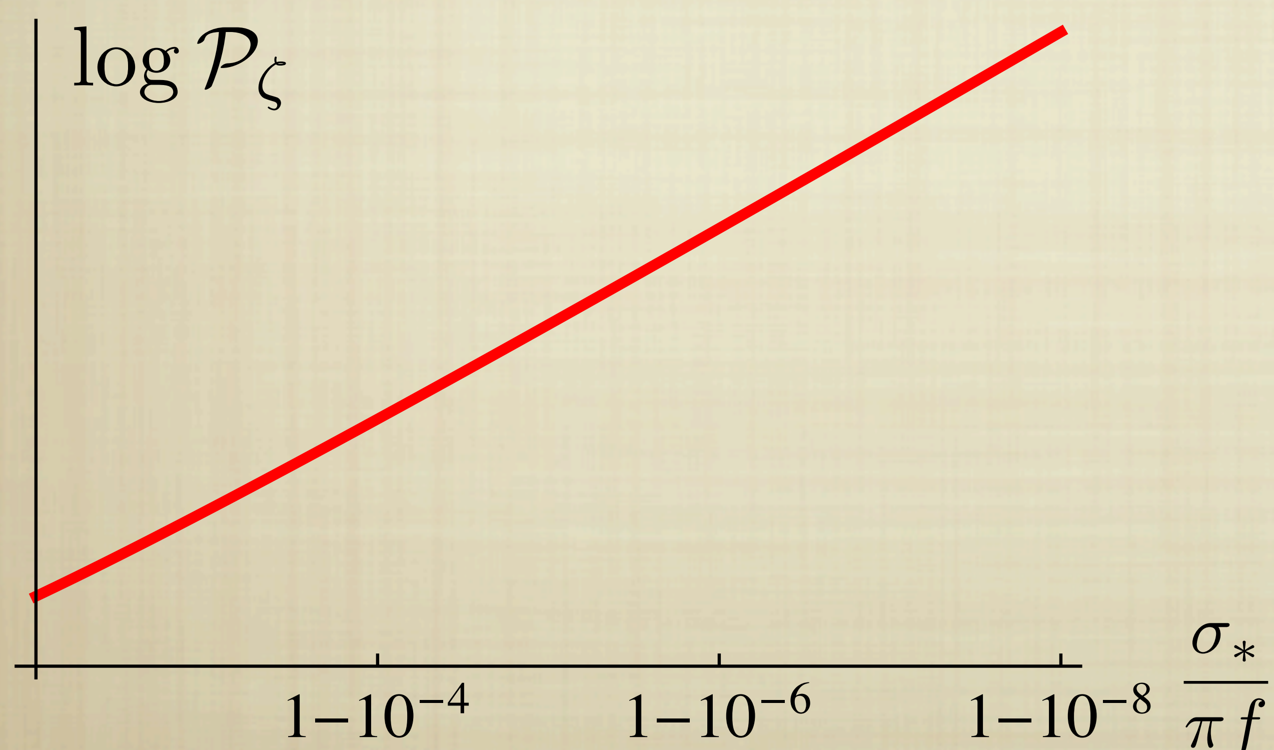

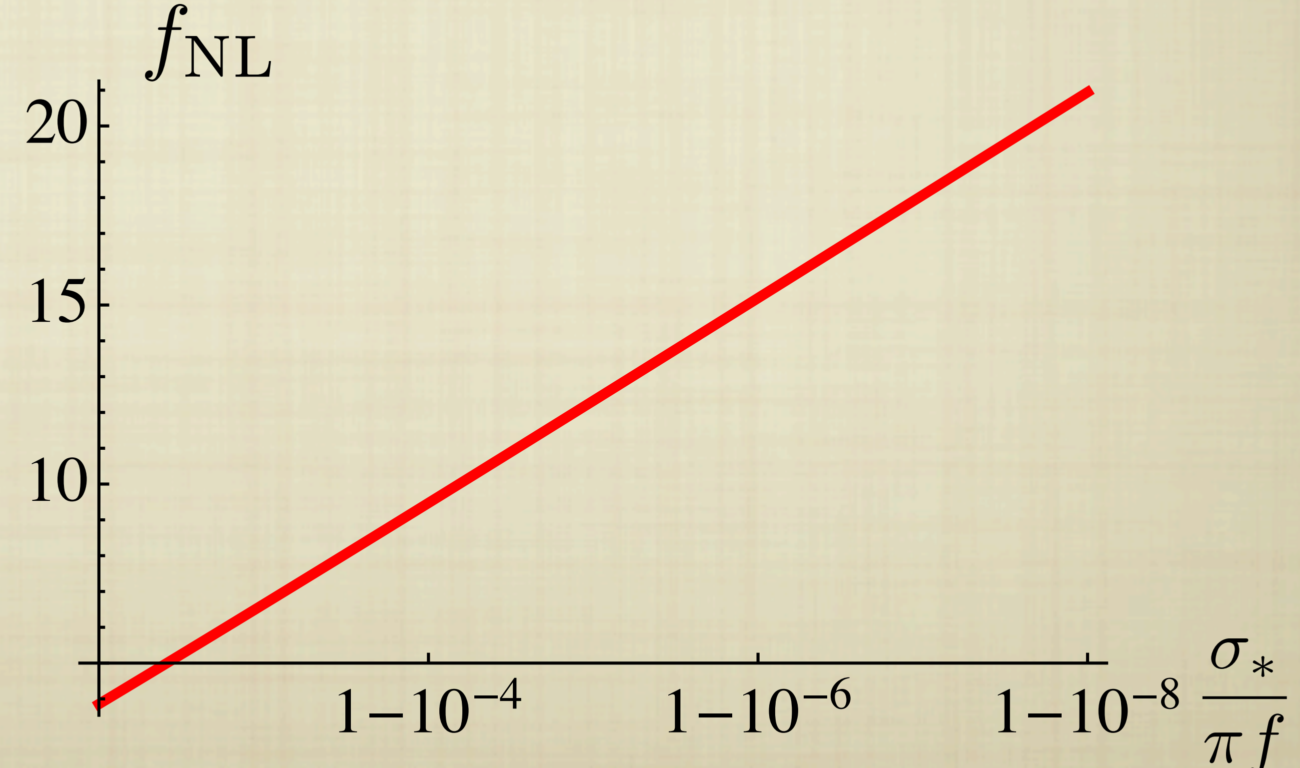

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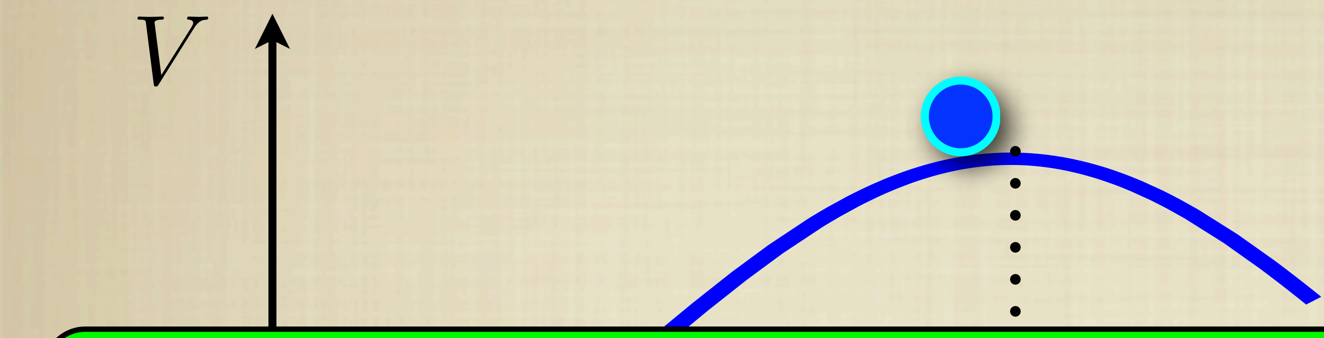
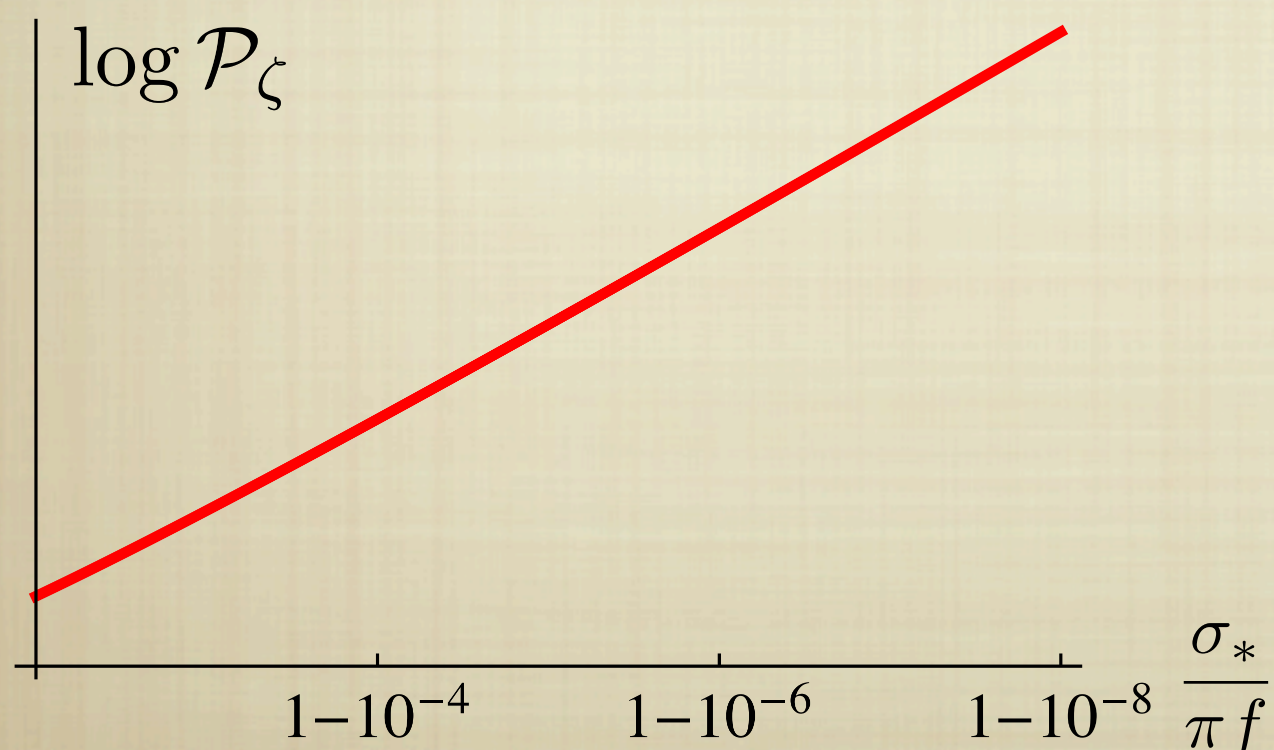
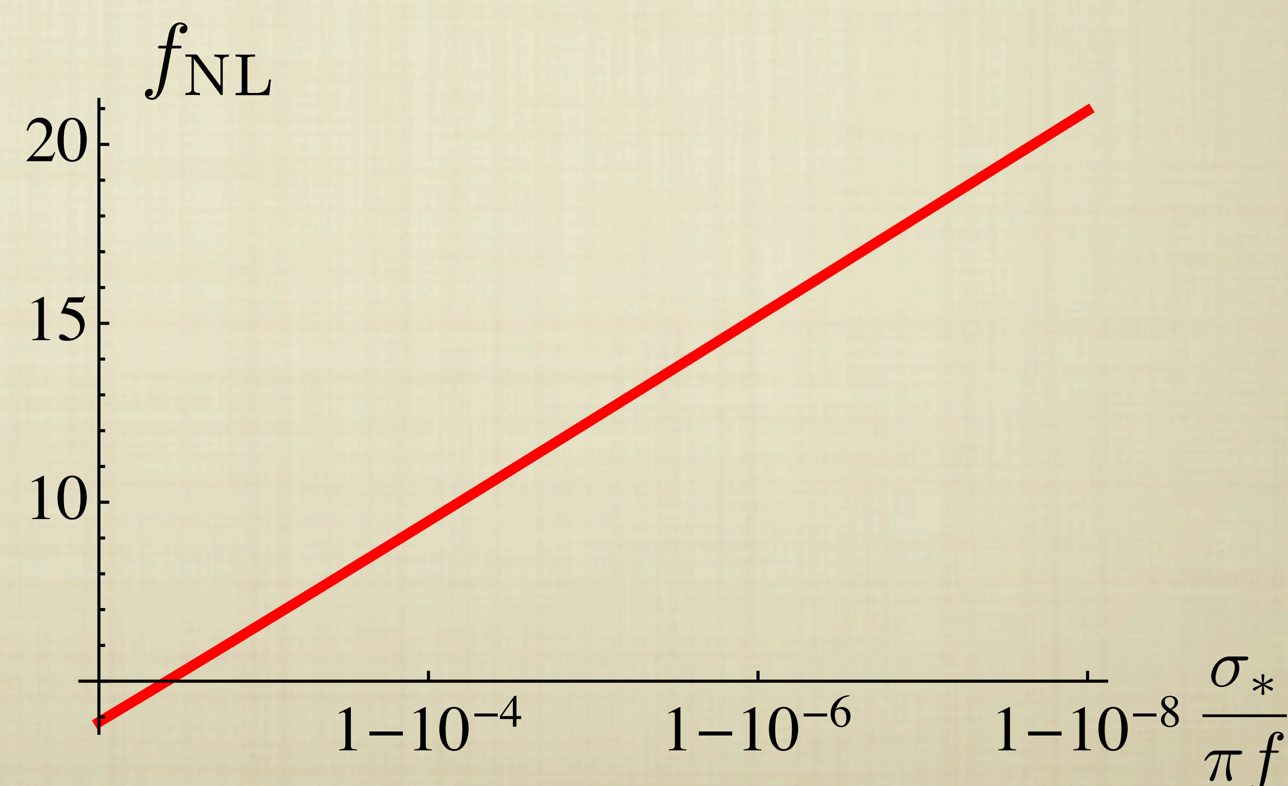


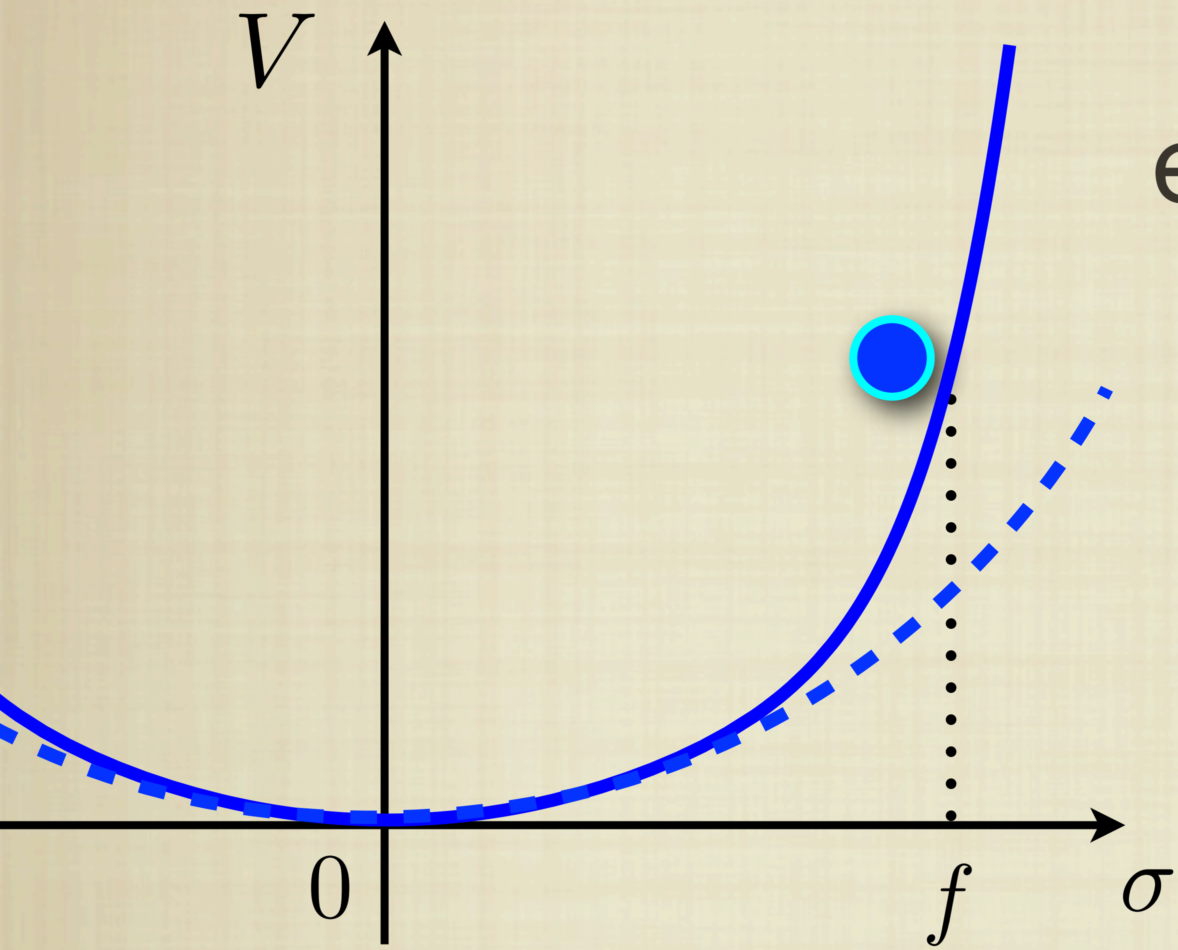
curvaton dominant case,

Strong enhancement of linear-order density pert. with mildly increasing f_{NL} of O(10) towards the hilltop.





2. Steep Potentials

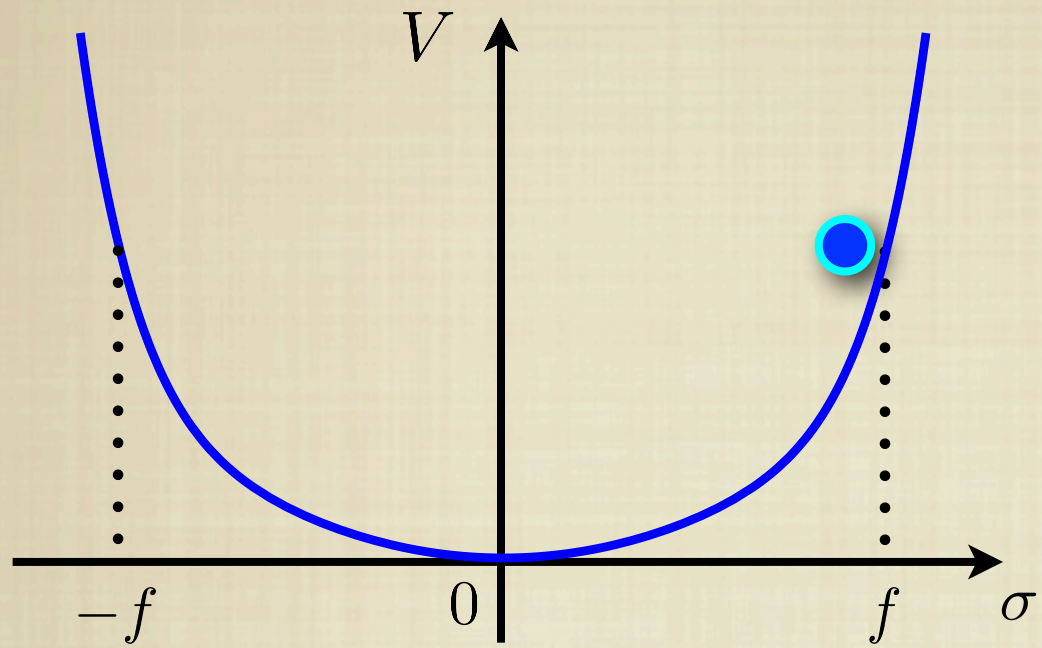


e.g. Self-Interacting Curvatons

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

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

Self-Interacting Curvatons



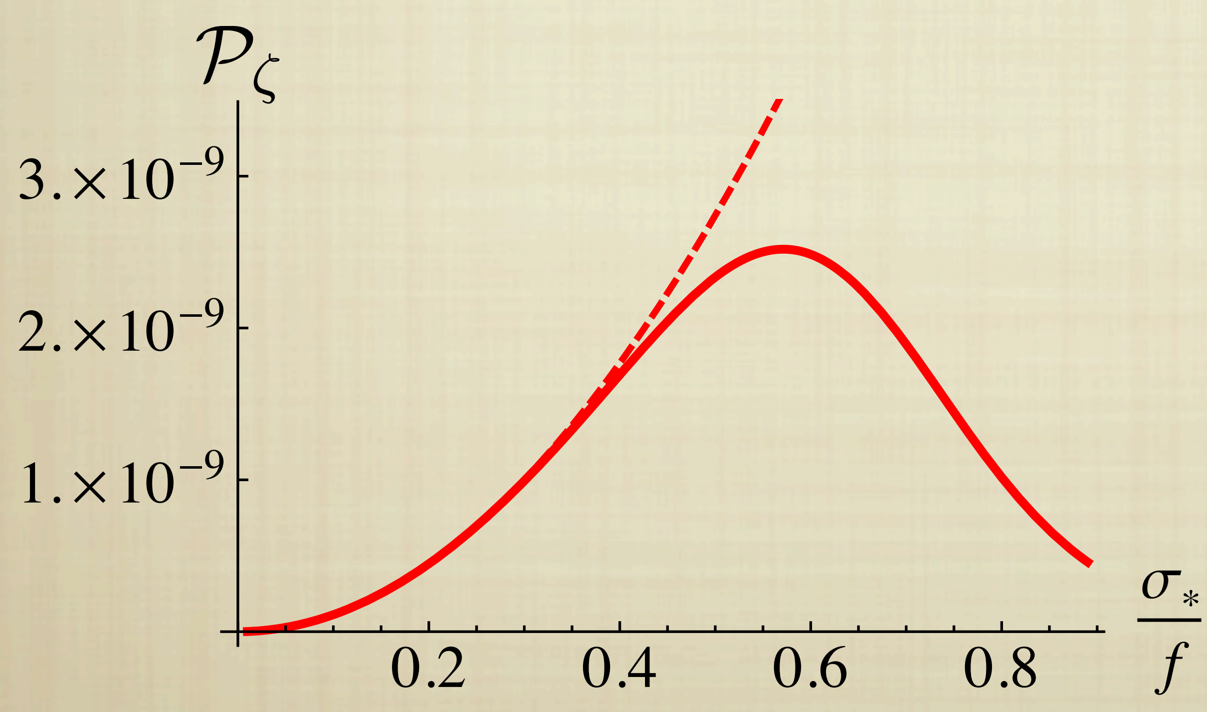
$$V(\sigma) = \Lambda^4 \left[\left(\frac{\sigma}{f}\right)^2 + \left(\frac{\sigma}{f}\right)^8 \right]$$

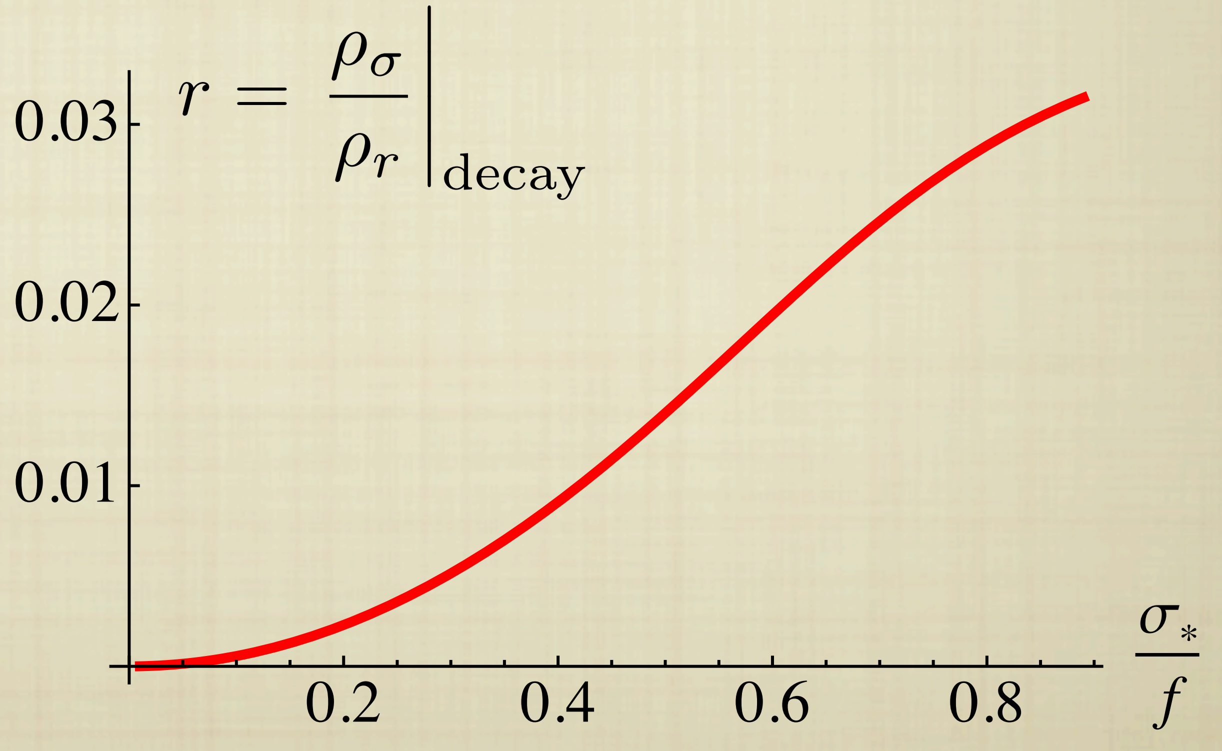
ex.) $\Lambda \sim 10^{12}\mathrm{GeV}$ $\quad f \sim 10^{13}\mathrm{GeV}$

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

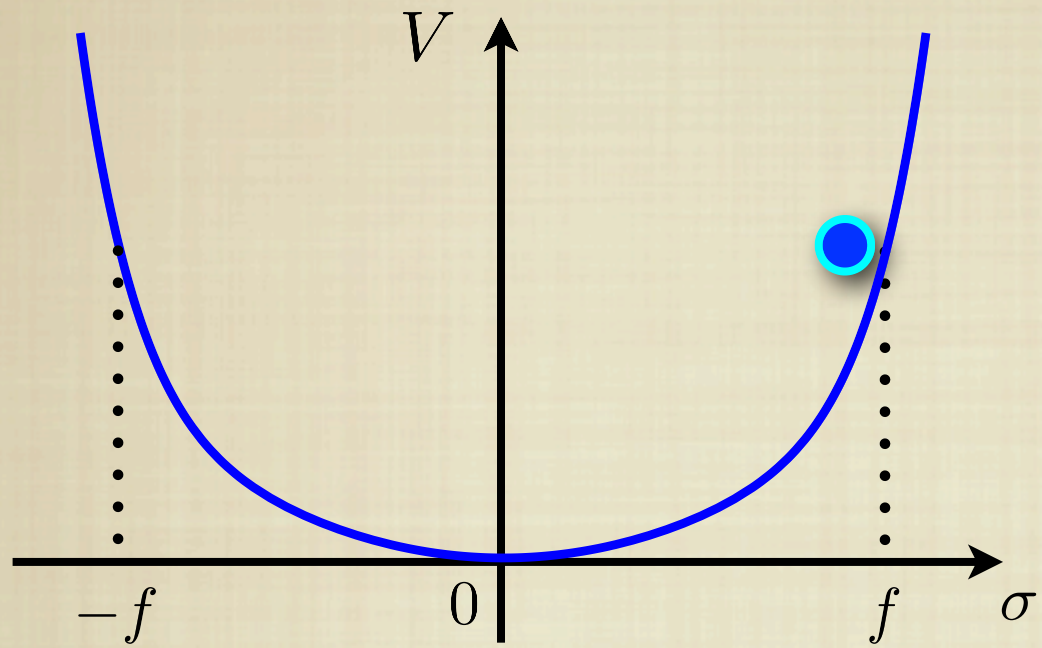
$T_{\mathrm{dec}} \sim 100\mathrm{GeV}$

When varying σ_* :





Self-Interacting Curvatons



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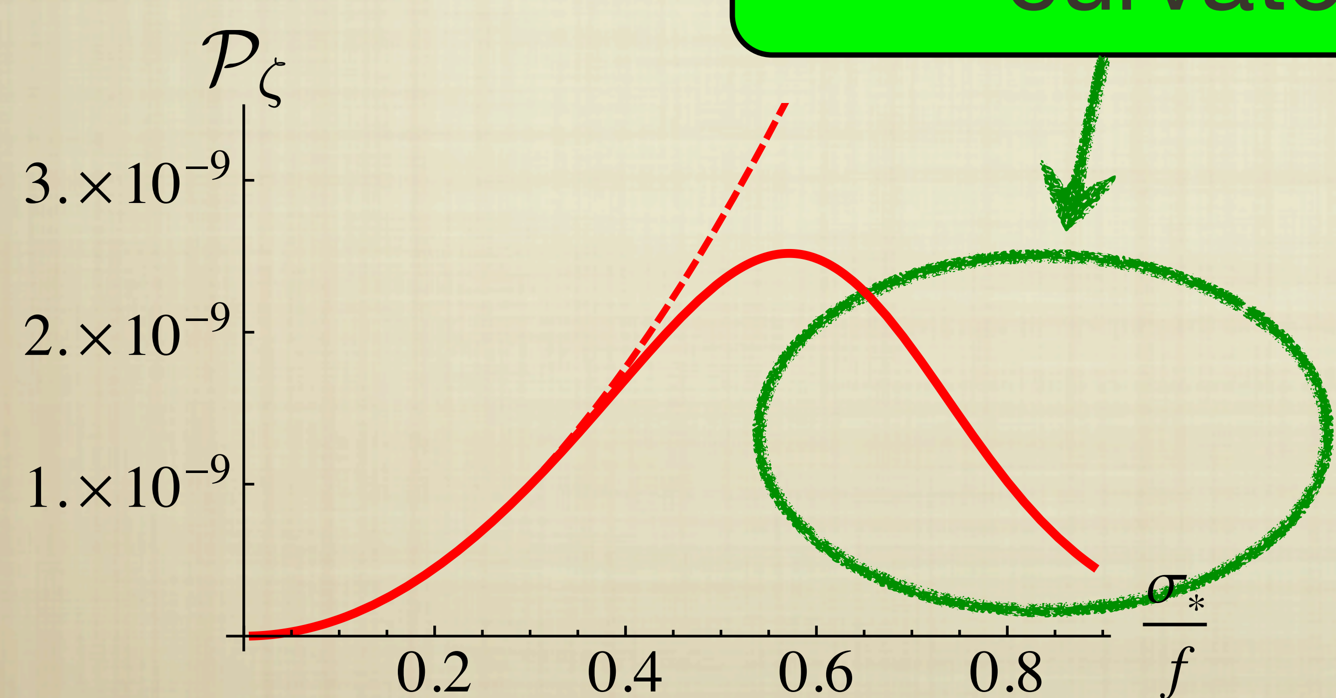
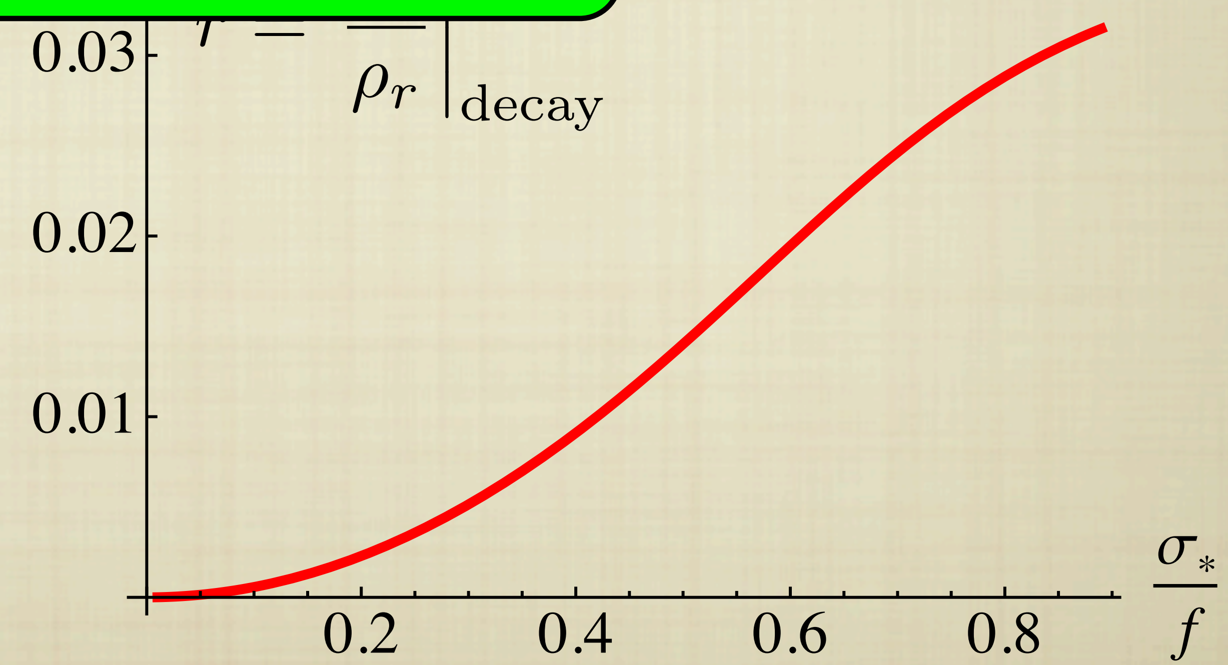
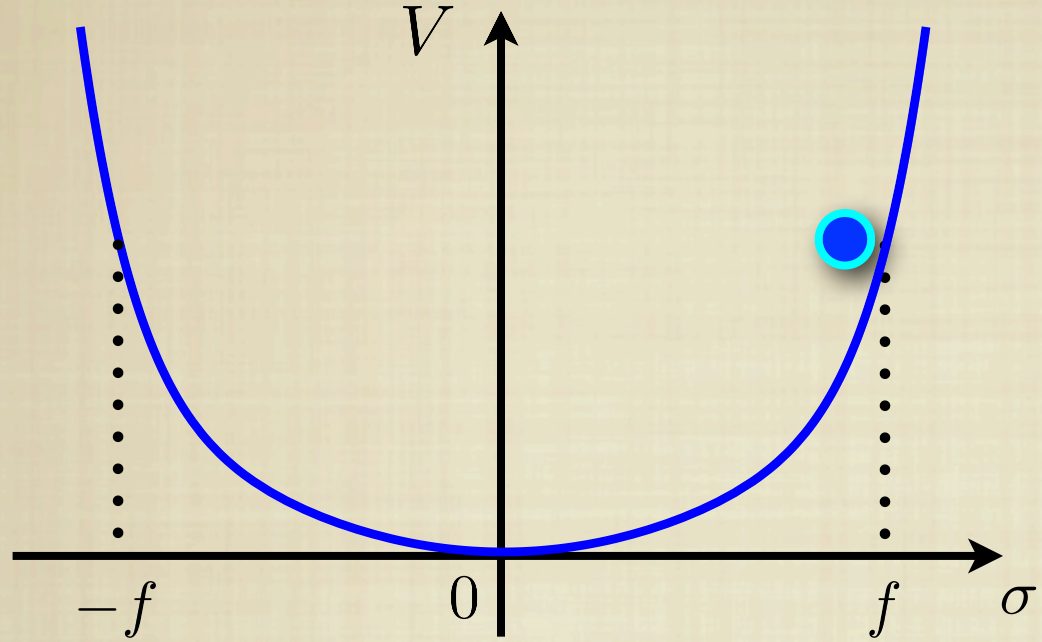
When varyin

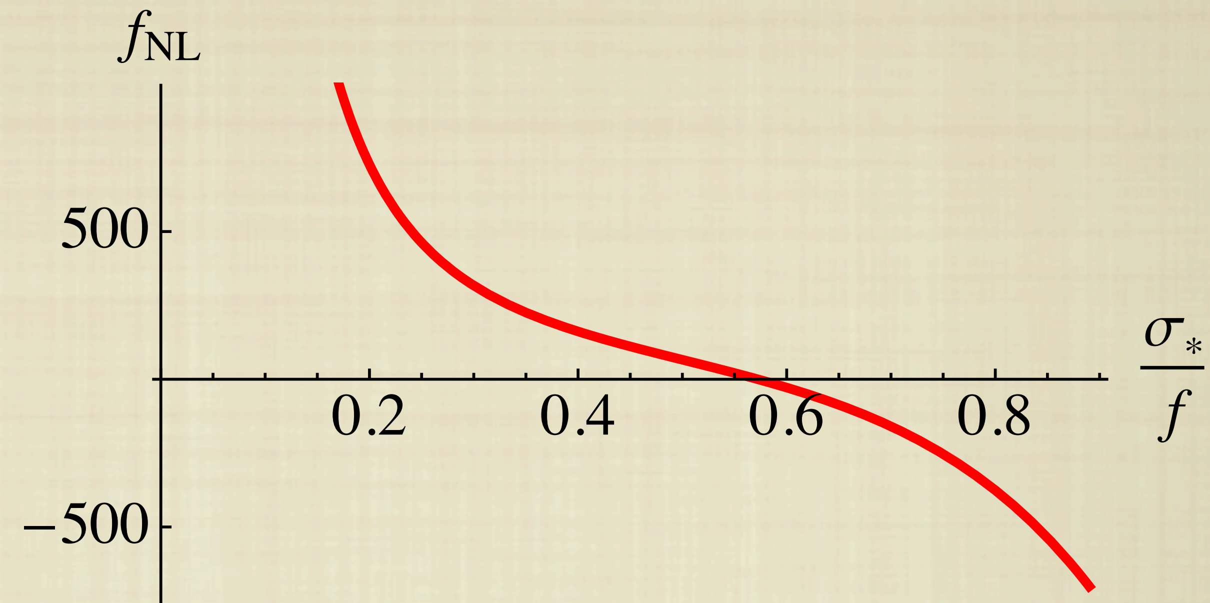
suppression due to
curvaton rolling





Self-Interacting Curvatons





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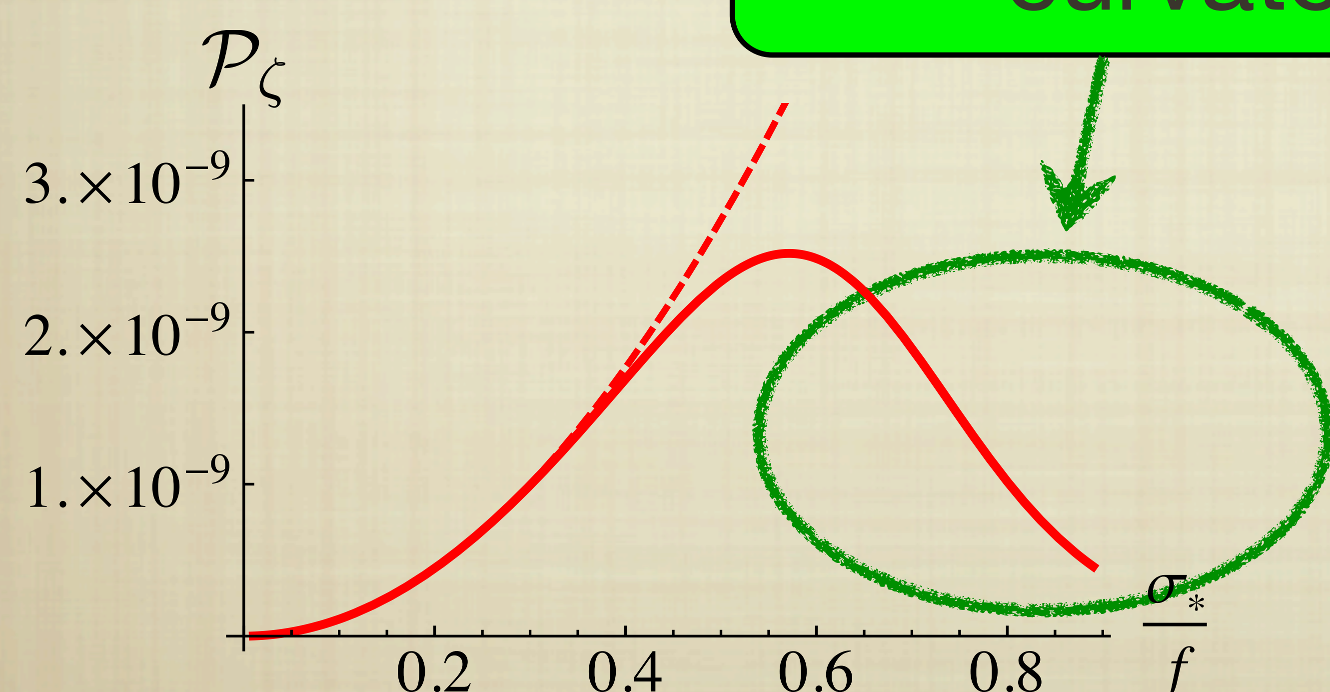

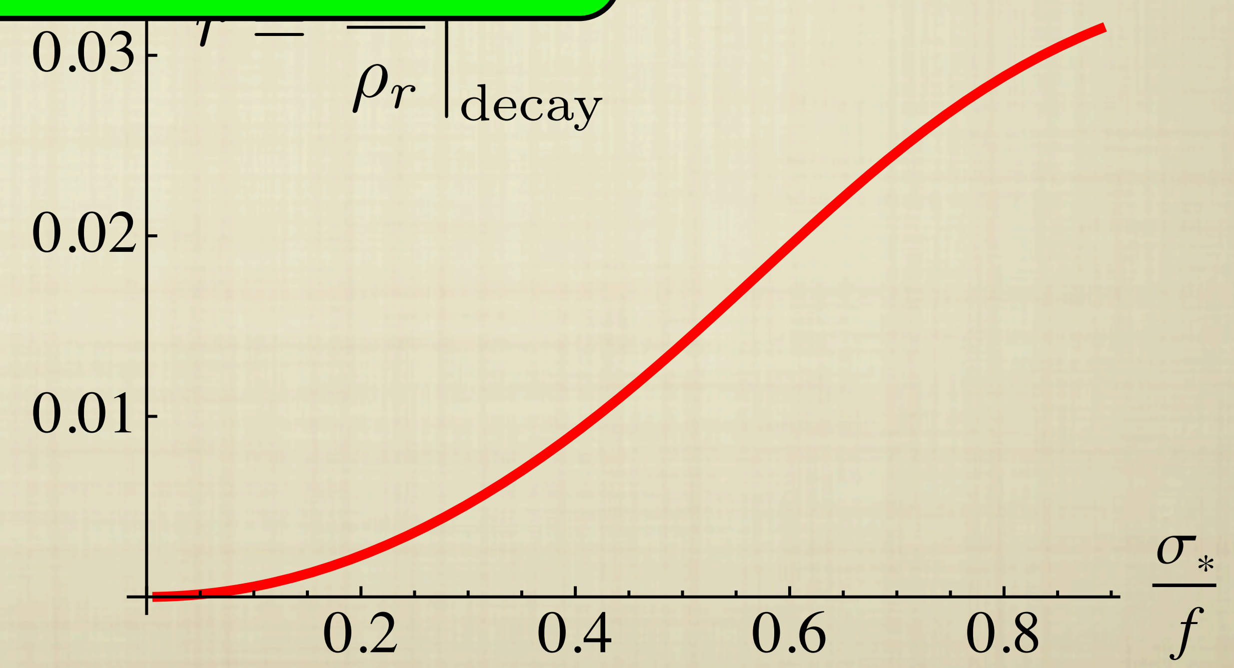

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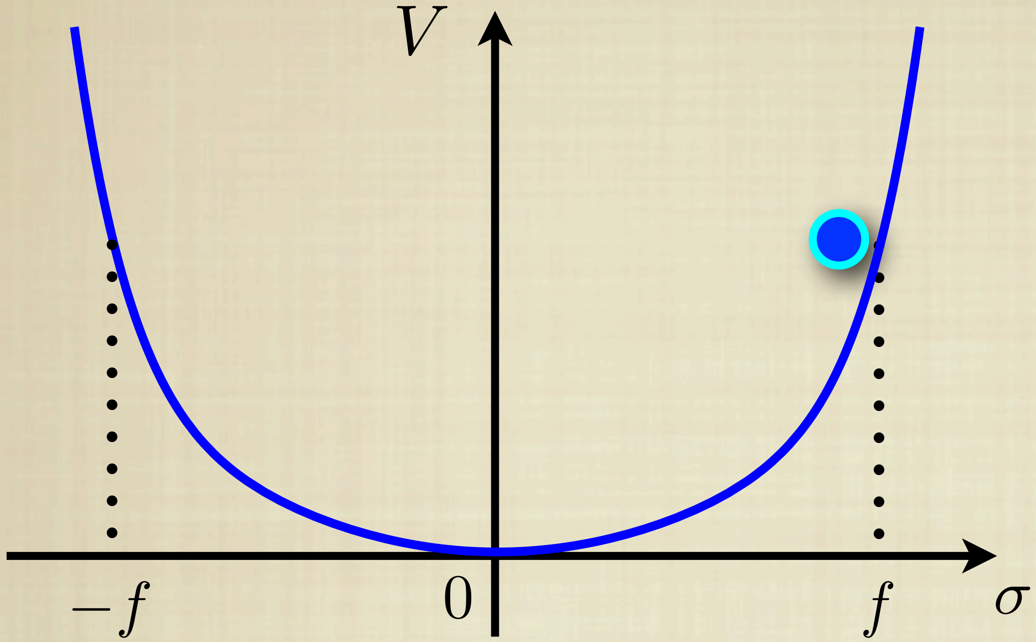

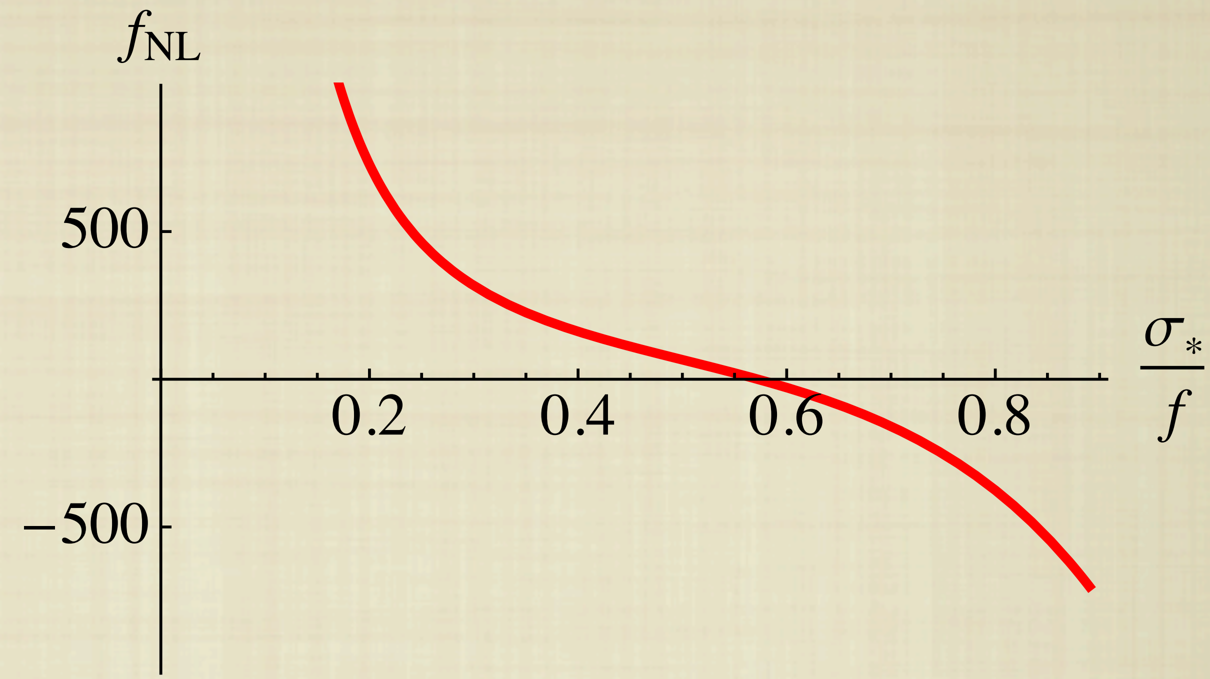

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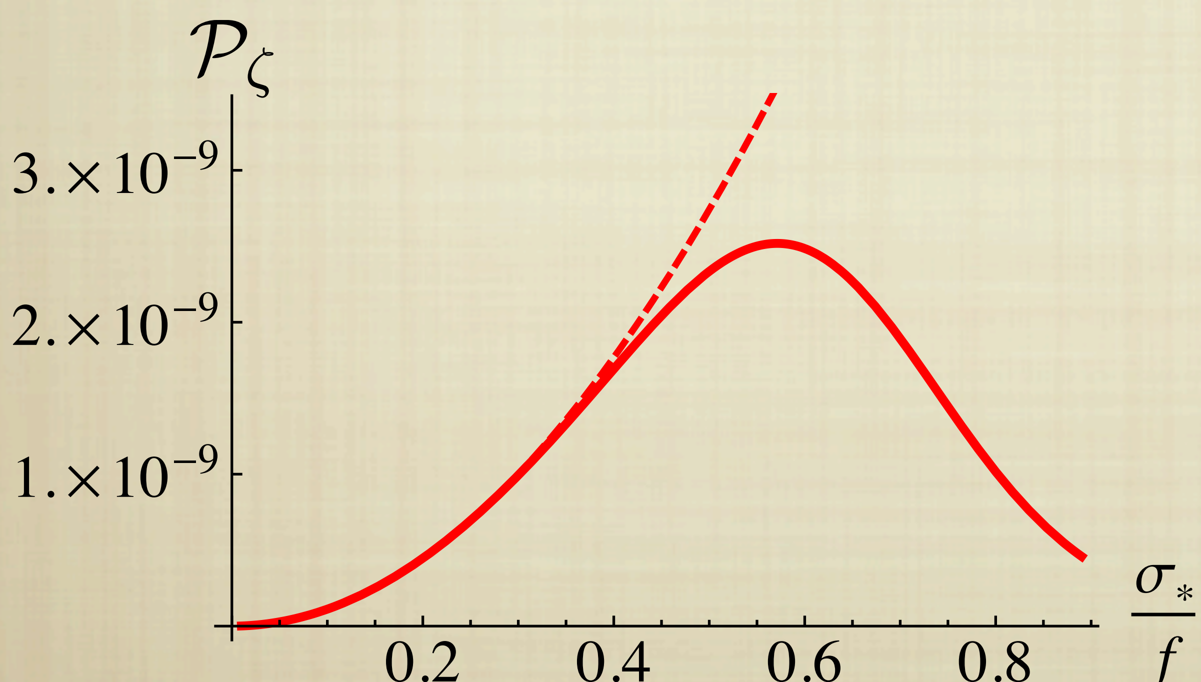
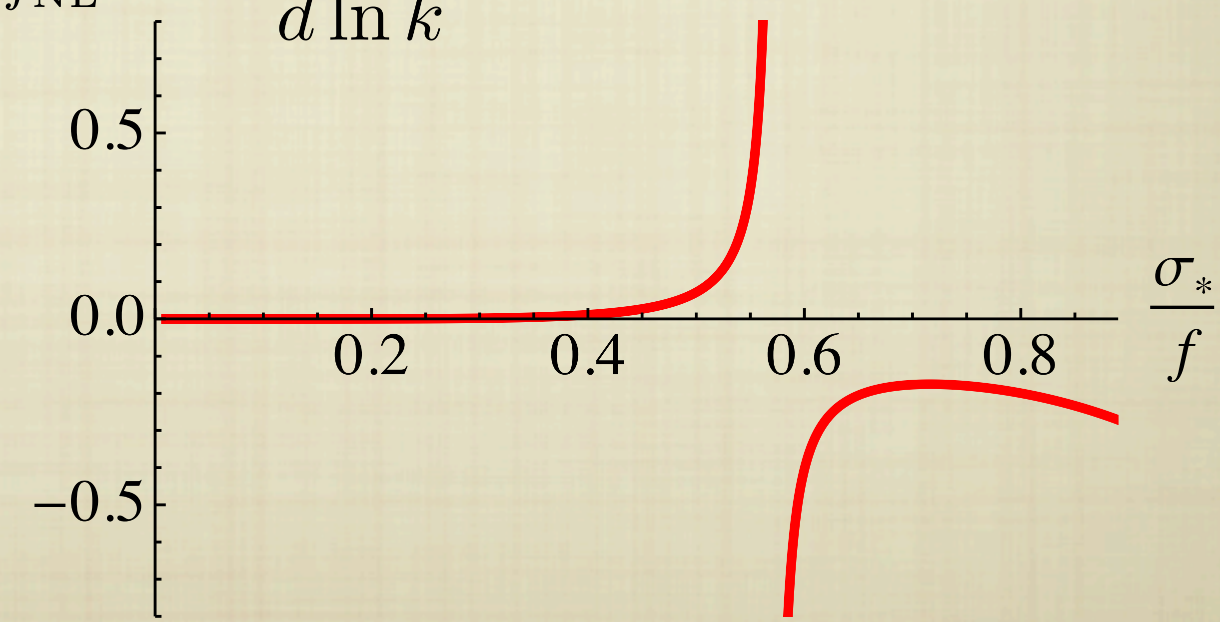
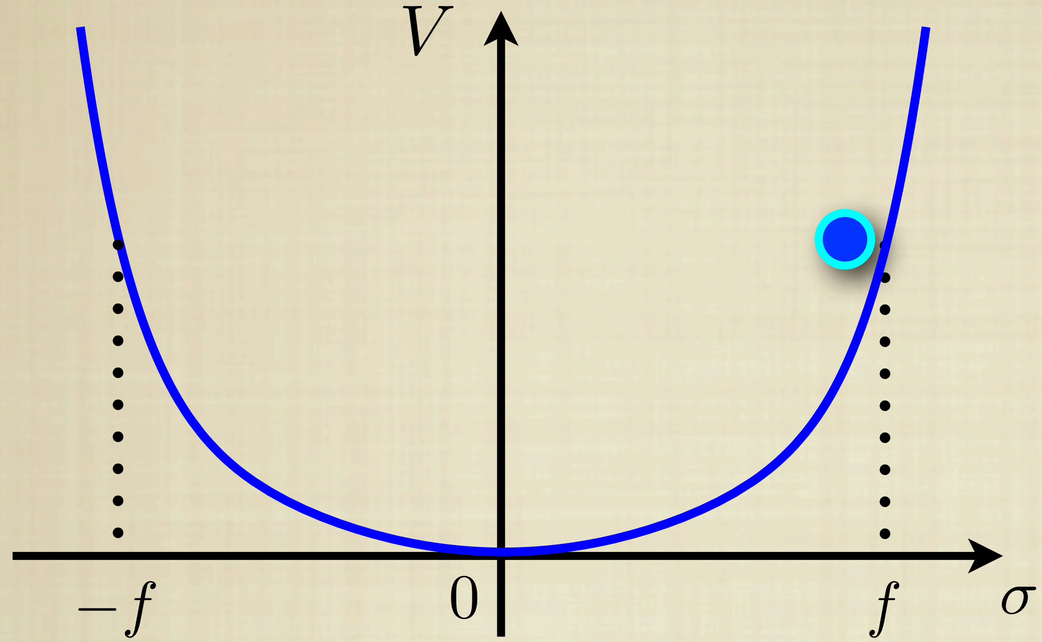


$$n_{f_{\mathrm{NL}}} = \frac{d \ln |f_{\mathrm{NL}}|}{d \ln k}$$



Self-Interacting Curvatons



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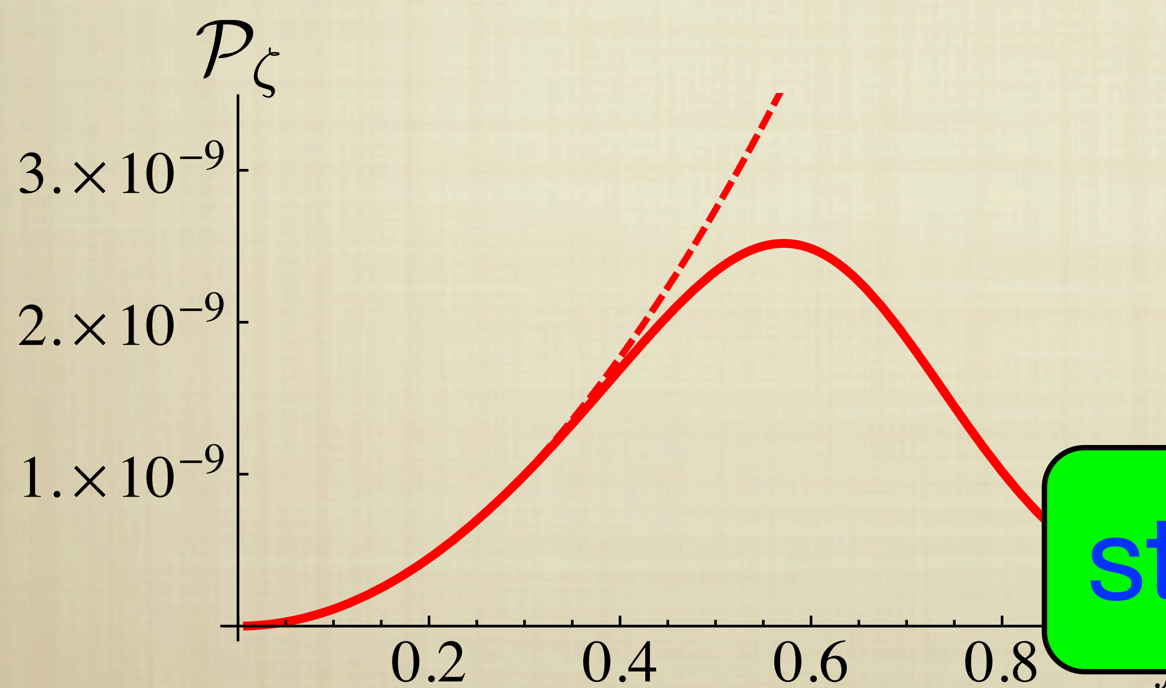

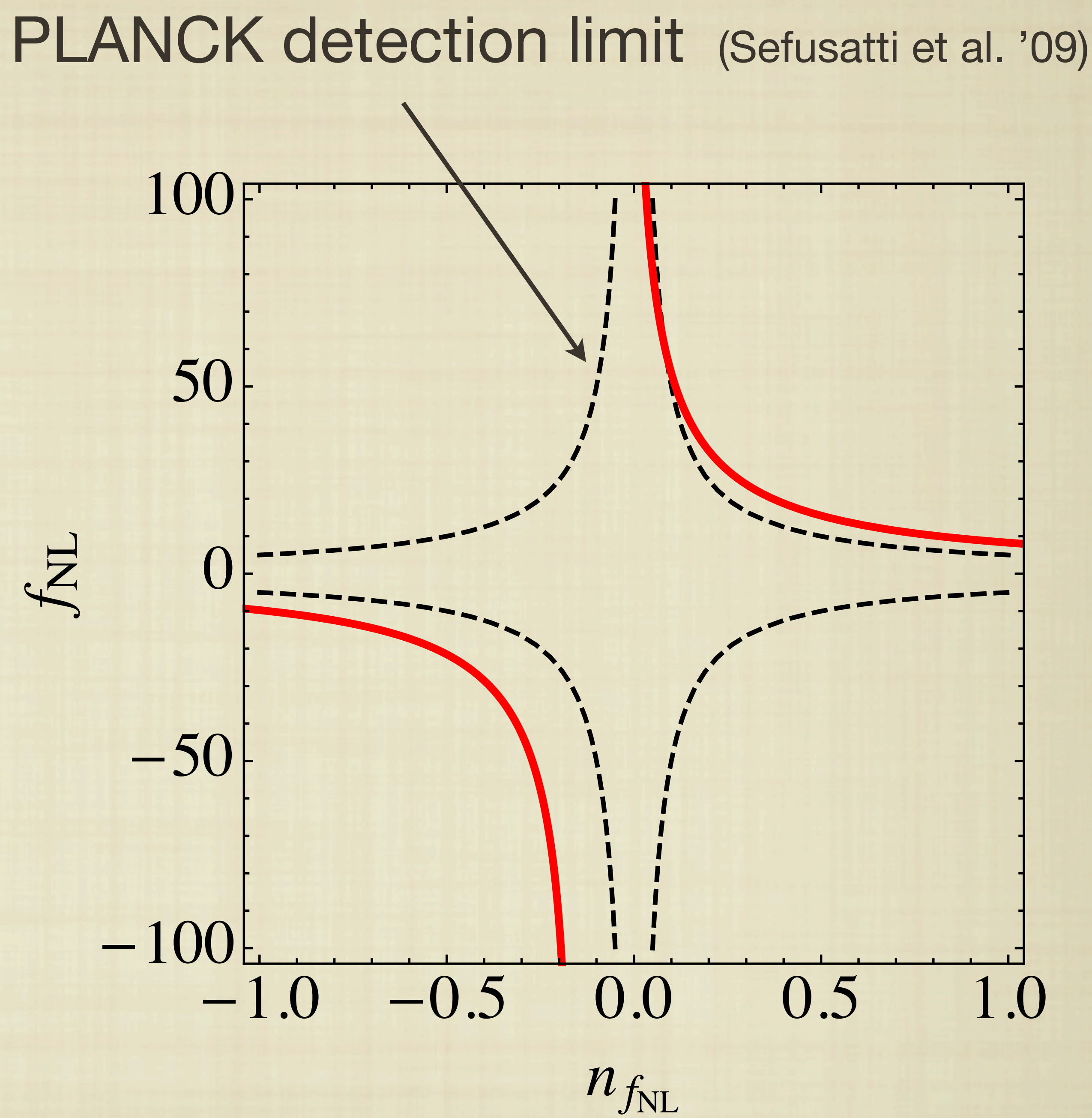

strongly scale-dependent f_{NL}

Summary

- We analytically investigated density perturbations from a curvaton with a generic energy potential.
- Non-quadratic curvatons exhibit new behaviors, such as inhomogenous onset of oscillations.
- 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.
- Future work : applications to microscopic models.