Corfu 2.9.2010

The self-interacting (subdominant) curvaton

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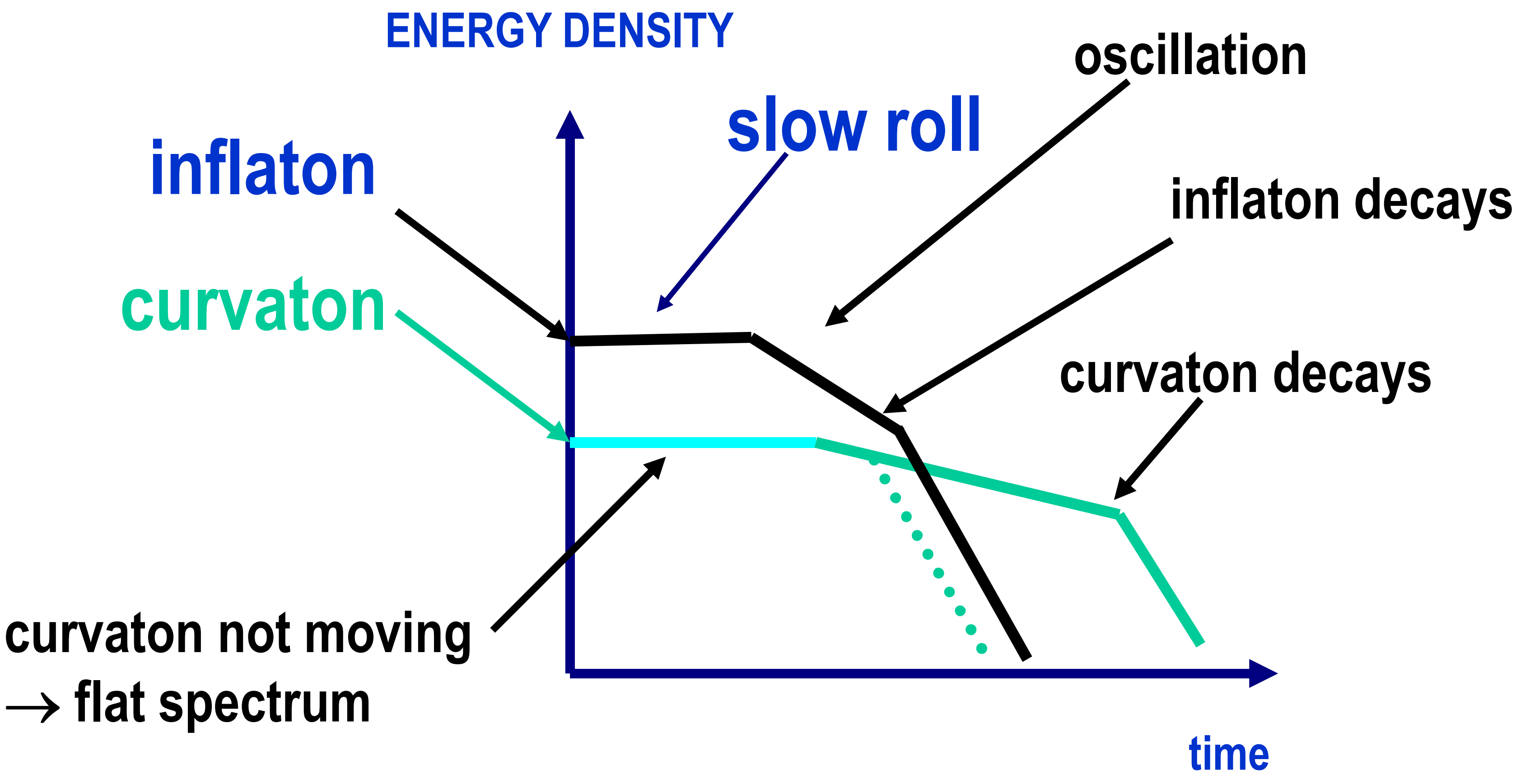
curvaton schematically

curvaton: massless field during inflation with $\rho_\sigma << \rho_\phi$



1. Curvaton dominant at decay $\rightarrow$ all matter from curvaton

matter inherits perturbation from the curvaton

2. Curvaton not yet dominant at decay $\rightarrow$ decay products thermalize with inflaton decay products

curvaton perturbation can be dominant if

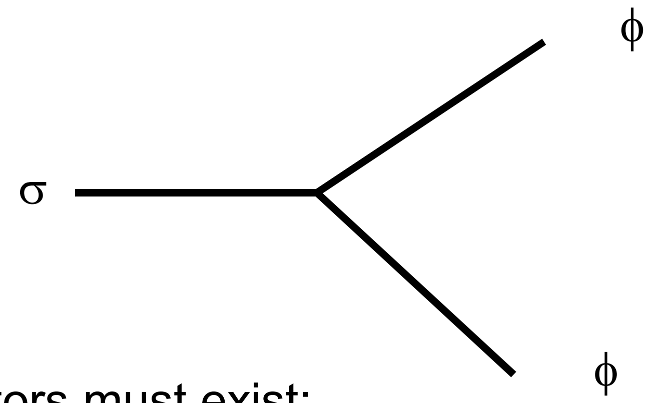
$$\frac{\delta\rho_\sigma}{\rho_\sigma} \gg 10^{-5} \qquad \textit{such that} \qquad \frac{\delta\rho_\sigma}{\rho_{tot}} = 10^{-5}$$

and inflaton perturbation small

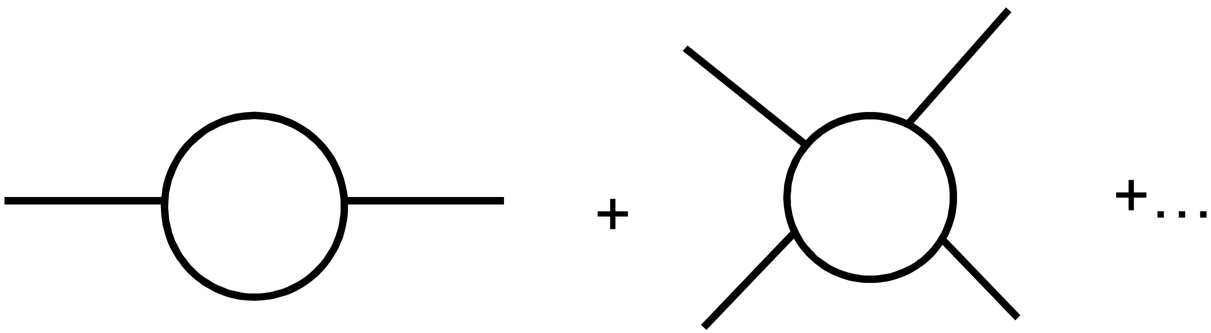
curvaton perturbation generated during curvaton oscillation from inflationary seed simplest potential $V = \frac{1}{2} m^2 \sigma^2$ $\Rightarrow$ $$\frac{\delta\sigma}{\sigma} = \frac{\delta\sigma_*}{\sigma_*}$$

initial value

curvaton must decay:



$\Rightarrow$ higher order operators must exist:



self-interactions

even weak interactions cosmologically important:

- large field values → probe interaction terms

- interactions → non-linearities

curvature perturbation at constant ρ hypersurface

$$\varsigma = \Delta N$$

separate universe formalism

$$N = N(\sigma) = \ln\left(a / a_0\right)$$

depends on the field initial condition

during curvaton oscillations

$$N \approx O(10) \; but \; \Delta N \approx O(10^{-5})$$

non-linearities: sensitivity to the initial condition

- in particular: non-gaussianity

$$\zeta = N'\delta\sigma_* + \tfrac{1}{2}N''(\delta\sigma_*)^2 + \tfrac{1}{6}N'''(\delta\sigma_*)^3 + \ldots$$

$$\zeta = \zeta_1 + \frac{3}{5} f_{NL} \zeta_1^2 + \frac{9}{25} g_{NL} \zeta_1^3 + \ldots$$

gaussian (ζ_1)

g_{NL}: connected part of 4-point correlator

τ_{NL}: disconnected part

$\langle \zeta\zeta \rangle$ spectrum $\langle \zeta\zeta\zeta \rangle$ bispectrum $\langle \zeta\zeta\zeta\zeta \rangle$ trispectrum

=0 for gaussian perturbation

non-gaussianity of the primordial perturbation
very important observable

… perhaps the single most interesting that Planck will measure

Limits:

$$-9 < f_{NL} < 111$$

$$-3.5\times10^{5} < g_{NL} < 8.2\times10^{5}$$

single-field inflation $f_{NL} \approx O(\varepsilon) \ll 1$

multi-field inflation $f_{NL} \approx O(1)$

Planck expected to set limit to $f_{NL} \leq 5$

preheating may generate large non-gaussianities

non-gaussianity in curvaton models

$$r \equiv r_{dec} = \left(\frac{3\rho_\sigma}{4\rho_r + 3\rho_\sigma} \right)_{decay}$$

$$\sigma' = \frac{d\sigma_{osc}}{d\sigma_*}$$

=0 for quadratic case

$$\sigma_* = \sigma_{osc}$$

$$f_{NL} = \frac{5}{3} + \frac{5}{8} r - \frac{5}{3r} \left(1 + \frac{\sigma''\sigma}{\sigma'^2} \right)$$

can be large

non-quadratic case: more complicated

Assume "small" deviation from quadratic form

$$V = \tfrac{1}{2} m_\sigma^2 \sigma^2 + \lambda m_\sigma^4 \left(\frac{\sigma}{m_\sigma} \right)^p$$

$$s \equiv 2\lambda \left(\frac{\sigma_*}{m_\sigma} \right)^{p-2}$$

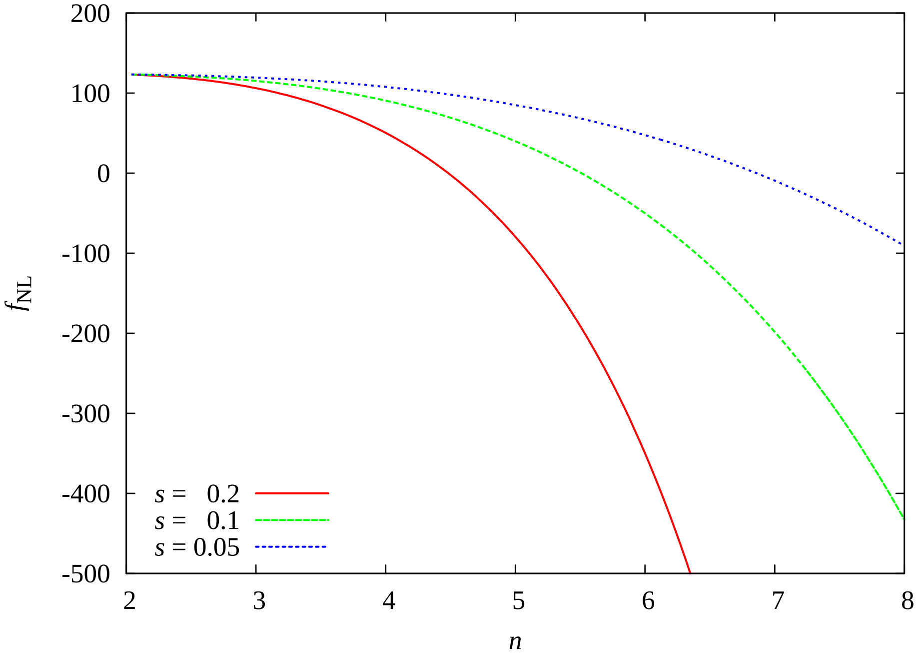
measures the strength of interaction

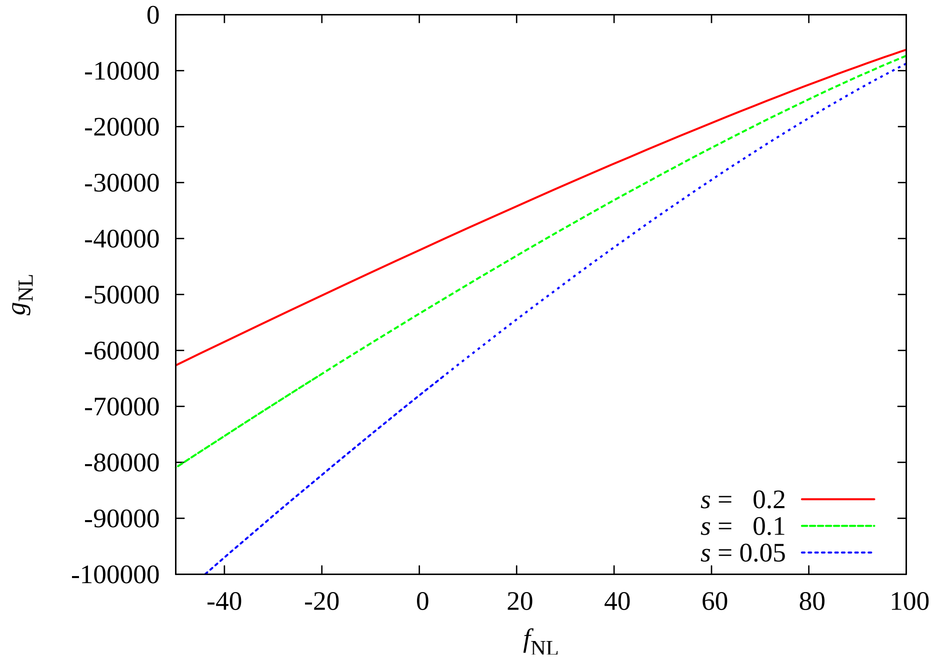
small: s<<2/p

non-integer p $\leftrightarrow$ logσ

$$V = \tfrac{1}{2} m_\sigma^2 \sigma^2 + \lambda m_\sigma^4 \left(\frac{\sigma}{m_\sigma} \right)^p$$

n=p

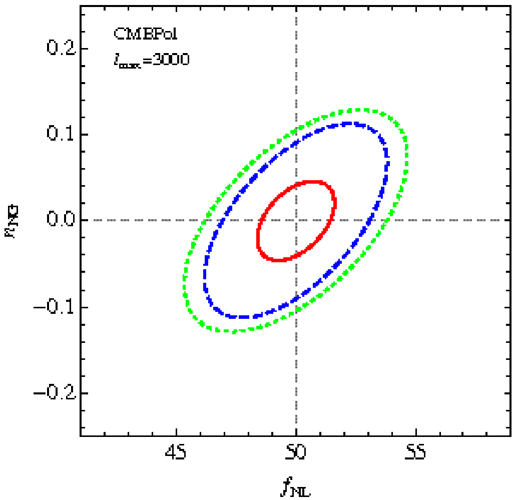




r=0.01

The spectral index of f_{NL}

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



Sefusatti et al, **JCAP 0912:022,2009**.

future resolution

$$\Delta n_{f_{NL}} \approx 0.05 \frac{50}{f_{NL}} \frac{1}{\sqrt{f_{sky}}}$$

If deviations are not always small ⇨ numerics

$$V = \tfrac{1}{2} m^2 \sigma^2 + \lambda \frac{\sigma^{4+n}}{M^n}$$

Equations of motion:

$$0 = \ddot{\sigma} + \left(3H + \Gamma\right)\dot{\sigma} + m^2\sigma + \lambda\left(n+4\right)\sigma^{n+3}$$

$$\dot{\rho}_r = -4H\rho_r + \Gamma\dot{\sigma}^2$$

$$3H^2 = \rho_r + \rho_\sigma$$

inflation

initial condition:

$$\sigma = \sigma_*,\ \sigma_+ = \sigma_* + \frac{H_*}{2\pi}$$

curvature perturbation is

$$\varsigma = N(\sigma_*) - N(\sigma_+)$$

for fixed *m, n,* free parameters are

$$H_*,\ r_* = \frac{\rho_\sigma}{\rho_r} \approx \frac{V(\sigma_*)}{3H_*^2} \square\ 1$$

⇒ find Γ at equal ρ such that $\varsigma = 10^{-5}$

"natural" value of $\sigma_* \leftrightarrow r_*$?

FP ⇒ $$P_{eq} \prec \exp\left(-\frac{8\pi^2}{3H_*^4} V(\sigma_*)\right)$$

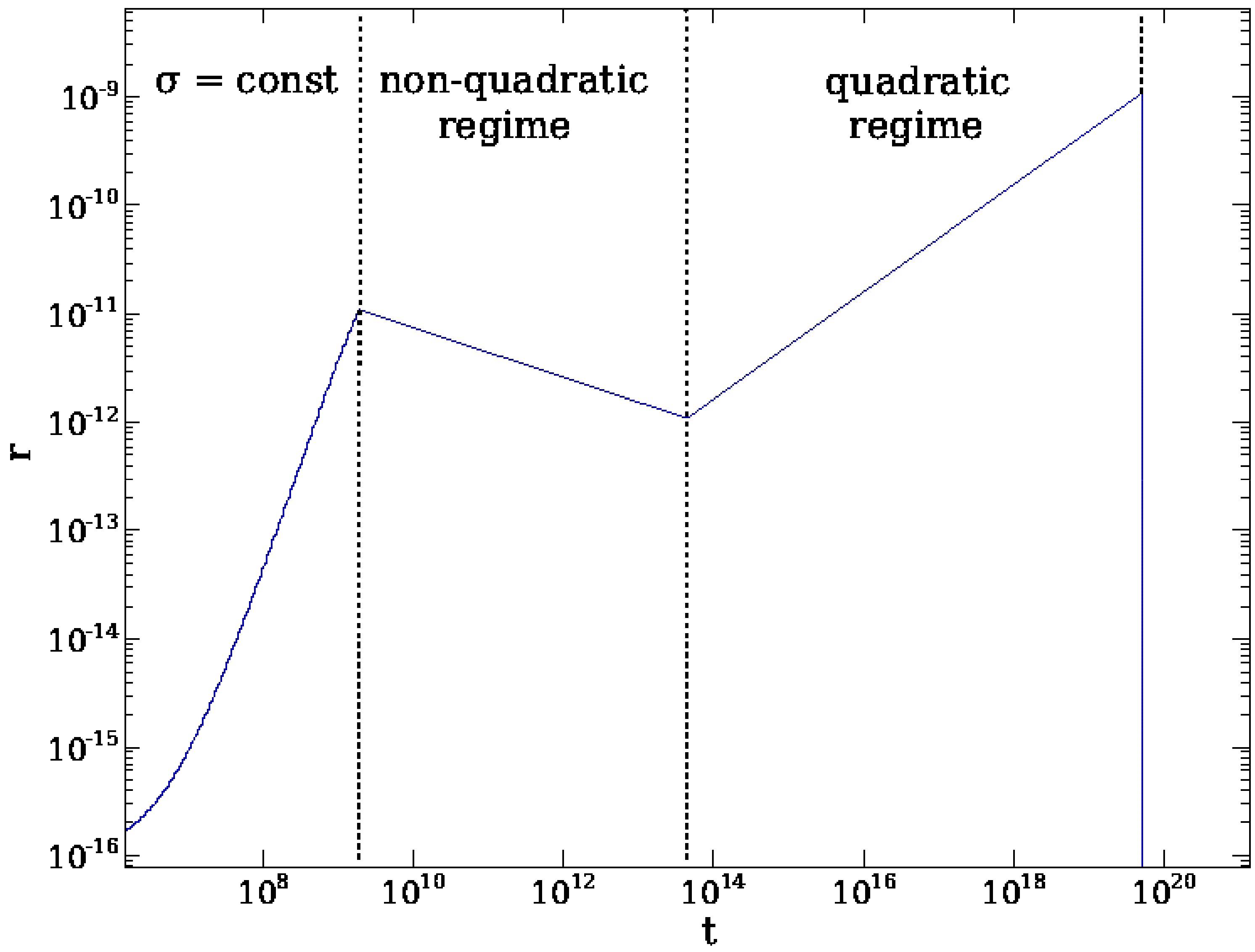
⇒ flat distribution up to $$V(\sigma_*) \approx \frac{H_*^4}{8\pi^2}$$

<u>*not*</u> quantum fluctuation = classical force $V' \approx H^3$

Four phases:

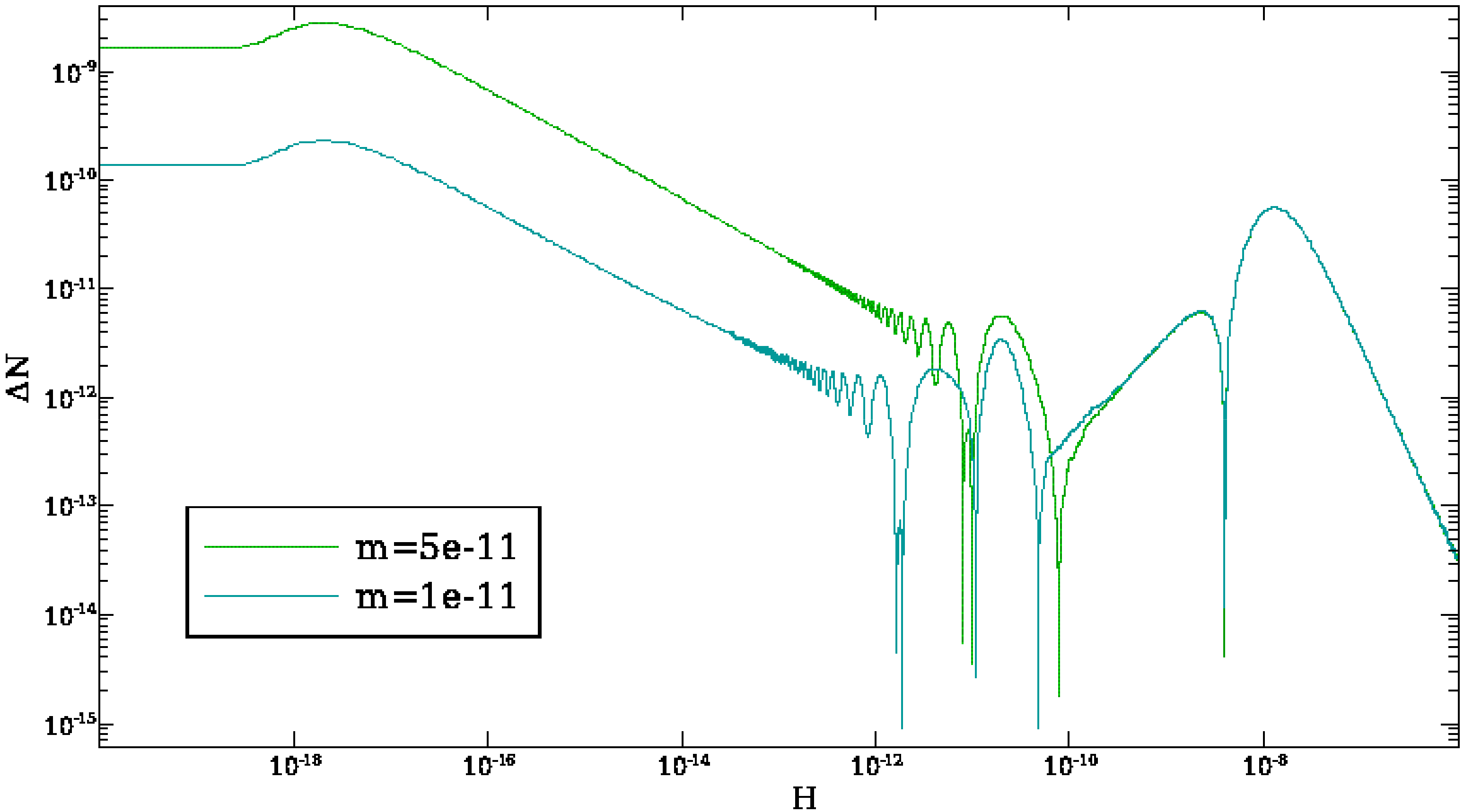
- slow roll $\sigma \approx \sigma_*$
- non-quadratic oscillation $\rho_\sigma \approx a^{-6\frac{n+4}{n+6}}$
- quadratic oscillation $\rho_\sigma \approx a^{-3}$
- decay $\Gamma \approx H$

scan through parameter space,
adjust parameters such that $\varsigma = 10^{-5}$



σ = const
non-quadratic regime
quadratic regime
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
r
10^{8}
10^{10}
10^{12}
10^{14}
10^{16}
10^{18}
10^{20}
t

perturbation sensitive to parameters:



contraint on Γ

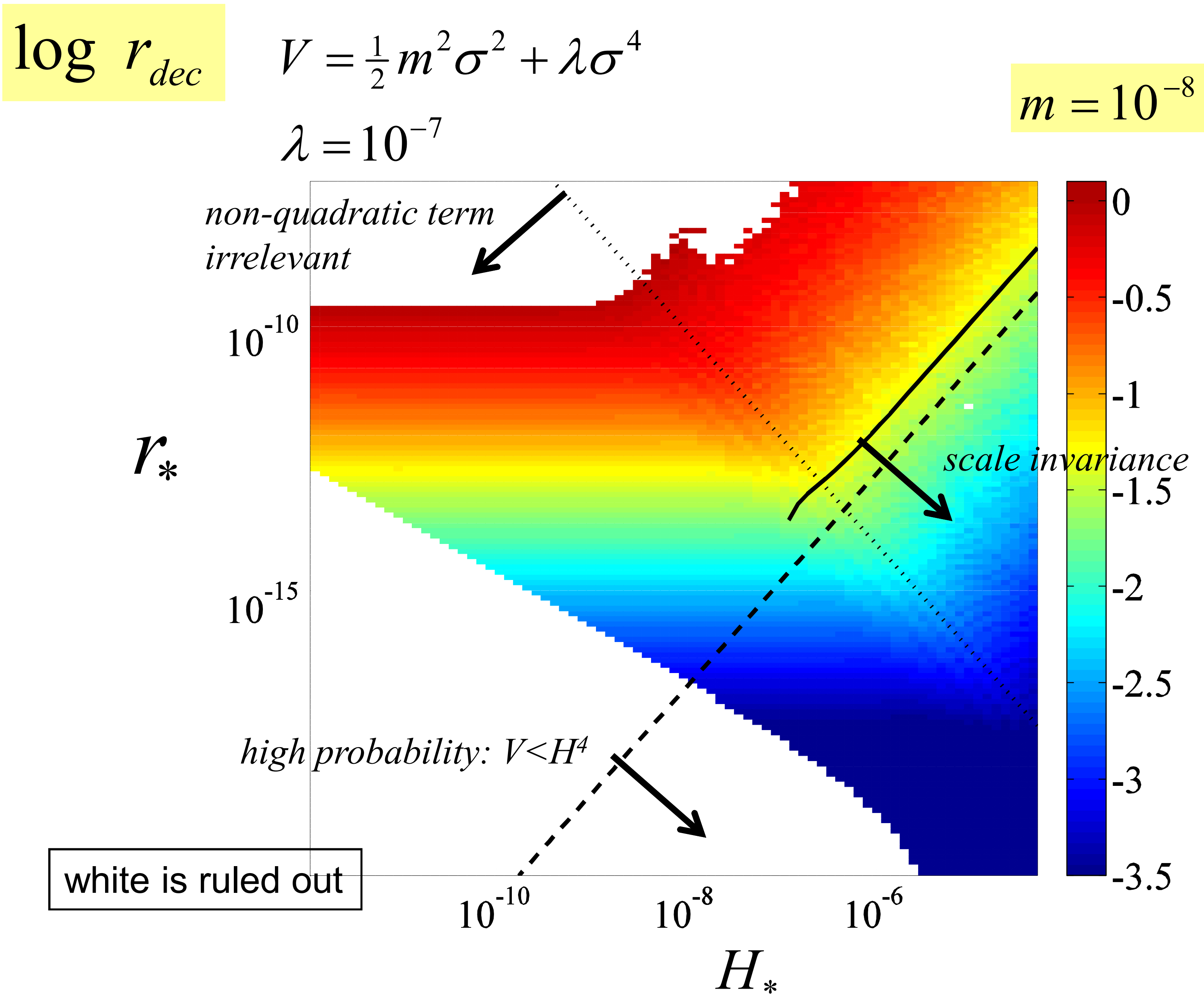
curvaton must decay before CDM freeze-out

perturbations adiabatic

$$\frac{M_{WIMP}}{T_{freeze}} \approx 20 \Rightarrow T_{freeze} \geq O(10)\ GeV$$

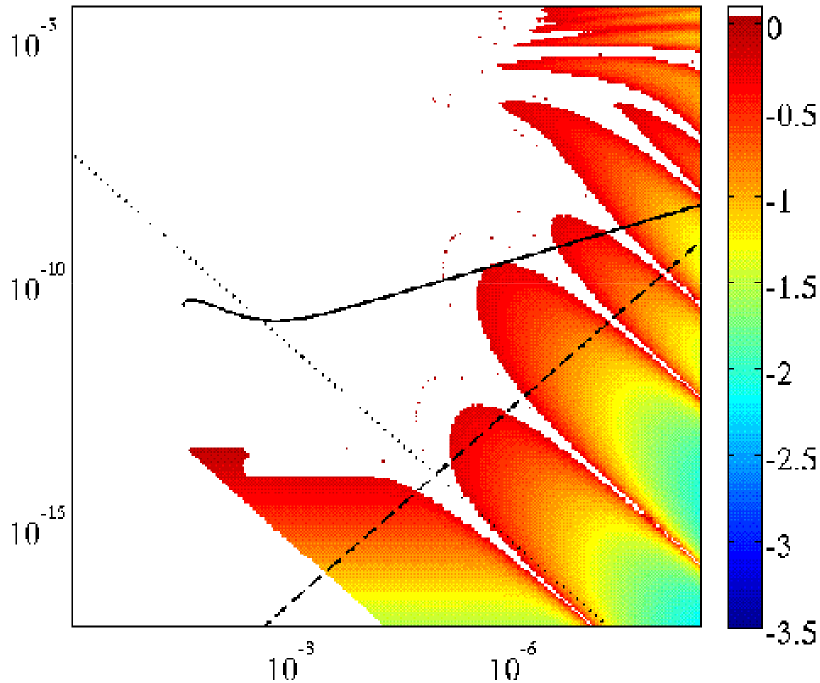
$$\Rightarrow \quad \Gamma \geq H_{freeze} \approx \frac{T_{freeze}^2}{M} \approx 10^{-15}\ GeV$$

spectrum scale invariant: $V'' < 10^{-2} H_*^2$



log r_{dec}
$V = \frac{1}{2}m^2\sigma^2 + \lambda\sigma^4$
$\lambda = 10^{-7}$
$m = 10^{-8}$
non-quadratic term irrelevant
scale invariance
high probability: $V<H^4$
white is ruled out
r_*
H_*
10^{-10}
10^{-15}
10^{-10}
10^{-8}
10^{-6}
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5

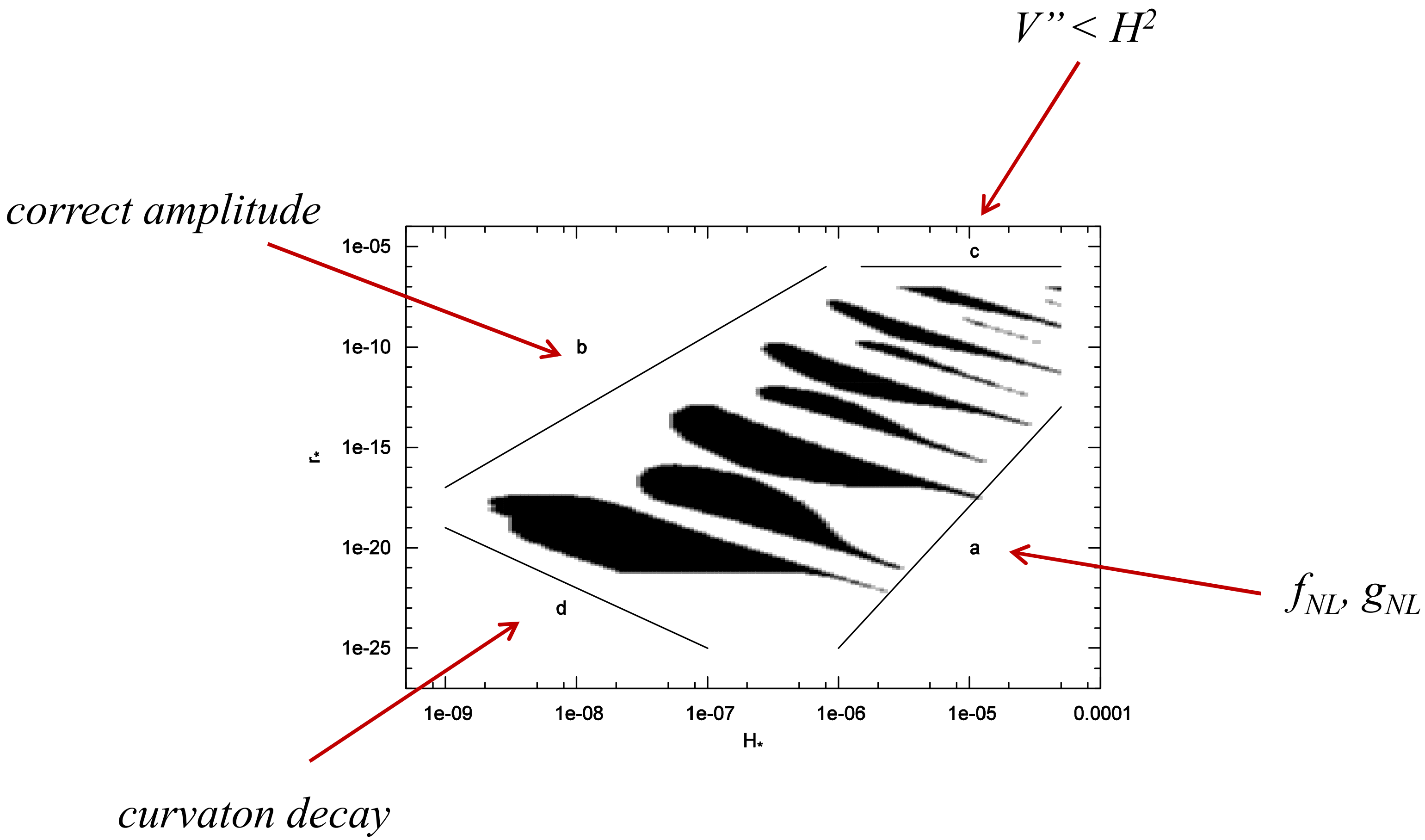
when non-linearities important, ΔN shows oscillations



$$n = 4,\, m = 10^{-12}$$

$$n = 4, m = 10^{-12}\ M$$

ALLOWED REGIONS



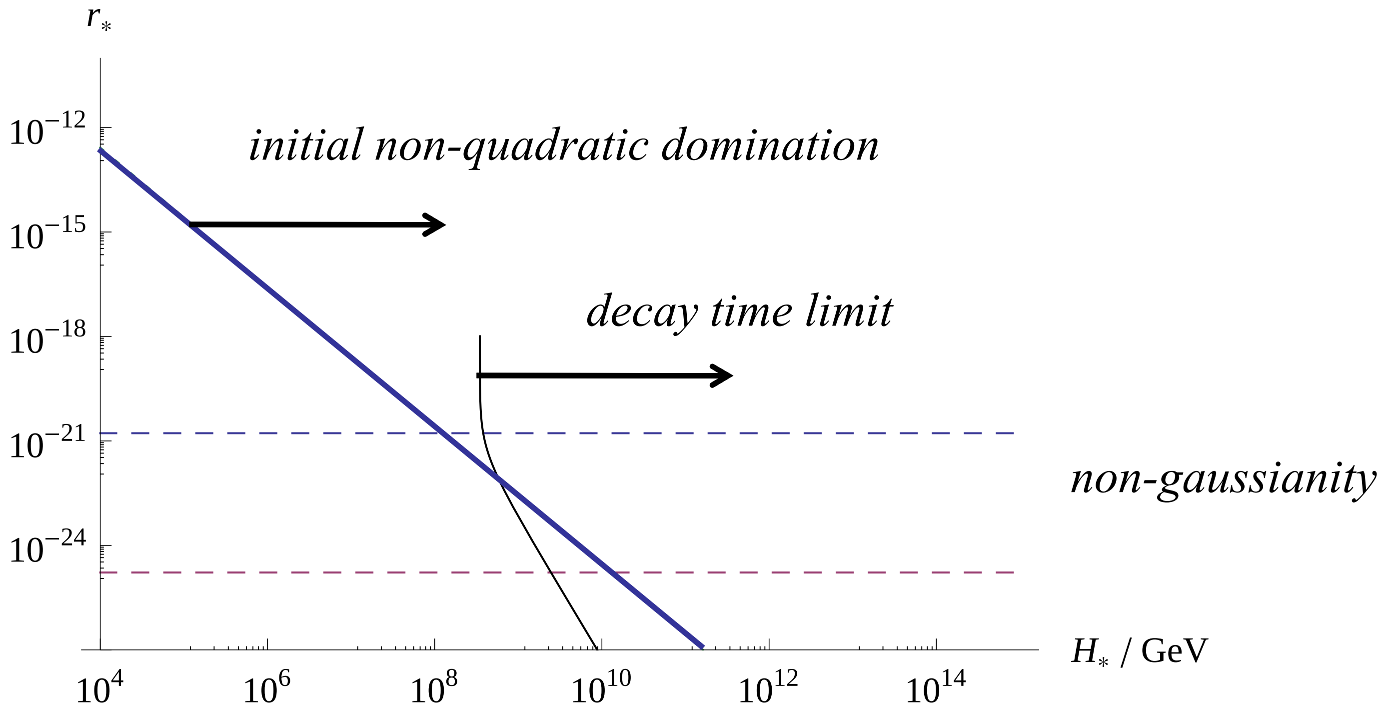
TeV scale curvaton?

if one assumes quadratic potential:

$$\varsigma = \frac{H_*}{\sigma_*} r_{eff} \approx 10^{-5} \quad , \qquad r_{eff} \approx r_{dec} = \frac{\rho_\sigma}{\rho_r + \rho_\sigma}$$

correct perturbation amplitude, non-gaussianity, decay before DM freeze-out

⇨ purely quadratic potential not consistent if m ~TeV n=4

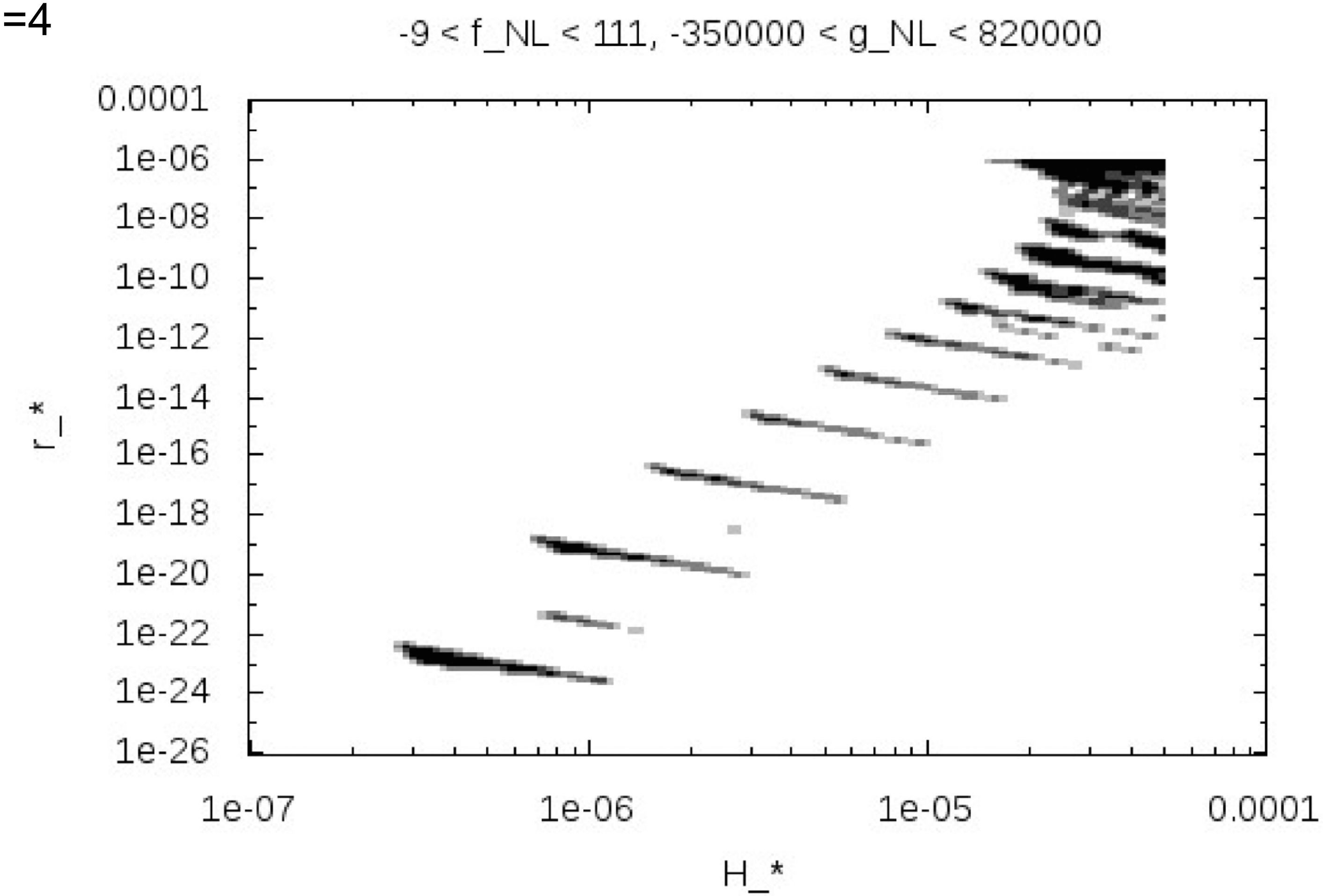


only n = 4 consistent ⇨

$$V = \tfrac{1}{2} m^2 \sigma^2 + \frac{\sigma^8}{M^4}, \quad m = O(1)\ TeV$$

allowed regions

n=4



What could the TeV scale curvaton be?

obvious candidates: MSSM flat directions

- can one have the required small Γ?

KE, Mazumdar, Taanila

conclusion

- ignore curvaton self-interaction at your peril
- rich phenomenology
- signature: large non-gaussianity
  - comp. bispectrum w. trispectrum
  - spectral index