Supercurvaton

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based on a work with **Andrei Linde** and **Viatcheslav Mukhanov**
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Motivations

Single field inflation predicts fluctuations which are almost scale-invariant and nearly Gaussian

Seven-year WMAP data:

E. Komatsu et al. (2010)

$$n_s = 0.968 \pm 0.012$$

$$-10 < f_{NL}^{obs} < 74$$

$$\mathcal{P}_s \sim k^{n_s - 1}$$

$$\frac{6}{5} f_{NL} = -\frac{B_\zeta(k_1, k_2, k_3)}{[P_\zeta(k_1) P_\zeta(k_2) + cyclic]}$$

Curvaton scenario:

model of inflation with two scalar fields

it allows a level of non-Gaussianity bigger than in single field inflation

Why Supercurvaton?

It would be nice to have a curvaton model as simple as the basic chaotic inflation scenario.

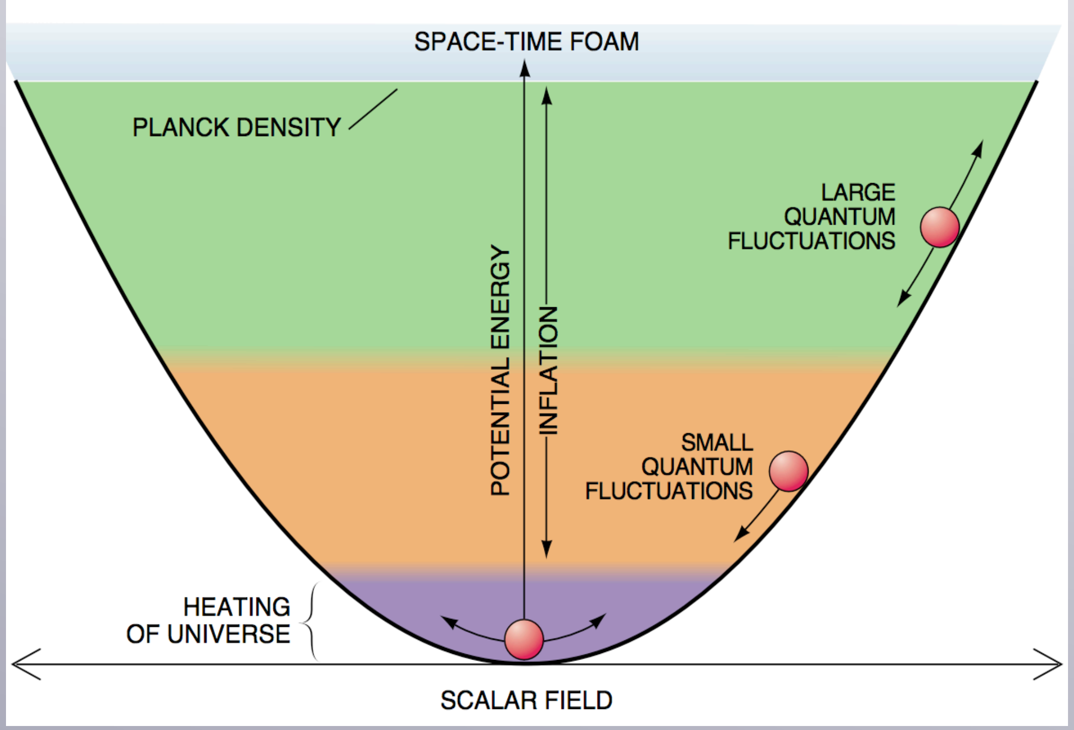
It would be good also to naturally implement this scenario in the context of supergravity.

Outline

- ➢ Chaotic inflation in supergravity
- ➢ Supercurvaton
- ➢ Level of non-Gaussianity: f_{NL}
- ➢ Conclusions

Chaotic inflation

$$V(\varphi) = \frac{1}{2}m^2\varphi^2$$



A. Linde

The inflaton can take any initial value provided that $(\partial_\mu\varphi)^2 \lesssim V(\varphi) \lesssim 1$

To cause inflation the inflaton must have a value larger than 1 : $\varphi > 1$

How can we implement chaotic inflation in supergravity?

M. Kawasaki, M. Yamaguchi and T. Yanagida (2000)

Problem:

the generic supergravity potential has an exponential factor $\exp(\Phi^*\Phi + \ldots)$ which prevents any scalar field Φ from having values larger than 1

Solution:

to introduce a shift symmetry of the inflaton, namely to assume that the Kähler potential is invariant under the shift symmetry of the inflaton

$$\mathcal{K}(\Phi, \Phi^*) = \mathcal{K}(\Phi - \Phi^*) \qquad e^{\mathcal{K}(\Phi - \Phi^*)}$$

However, as long as the shift symmetry is exact, the inflaton never has a potential and hence **it never causes inflation**

$\rightarrow$ small **breaking term** of the shift symmetry

$$W = mS\Phi$$

Supercurvaton

Let us consider a very simple model with two fields S and Φ

$$W = mS\Phi \qquad \mathcal{K} = SS^* - \frac{1}{2}(\Phi - \Phi^*)^2$$

Note that the Kähler potential does not depend on the phase of S and on the real part of Φ

$$\Longrightarrow \qquad S = \frac{\sigma}{\sqrt{2}} e^{i\theta} \qquad \Phi = \frac{1}{\sqrt{2}}(\varphi + i\chi)$$

φ plays the role of the **inflaton** with $V(\varphi) = \frac{m^2}{2}\varphi^2$

$m_\sigma^2 = m^2$ $\quad$ σ is the **curvaton field**

Taking $\chi = 0$ $\quad\rightarrow\quad$ $V(\varphi,\sigma) = \frac{m^2}{2} e^{\sigma^2/2}\left[\varphi^2 + \sigma^2 + \frac{\varphi^2}{4}\sigma^2(\sigma^2 - 2)\right]$

Expanding with respect to σ^2 and using the Friedmann equation

$$\begin{cases} \varphi\sigma \ll 1 & m_\sigma^2 = m^2 \\ \varphi\sigma \gtrsim 1 & m_\sigma^2 \sim \frac{3}{4}m^2\varphi^2\sigma^2 \simeq \frac{9}{2}H^2\sigma^2 > m^2 \end{cases}$$

supergravity corrections are important!

Note: $\sigma \gtrsim 1$ the potential becomes exponentially steep

⇩

$\sigma \lesssim 1$

For the rest of the talk we concentrate on the simplest model:

$$W = mS\Phi$$

$$\mathcal{K} = SS^* - \frac{1}{2}(\Phi - \Phi^*)^2 - \frac{\alpha}{12}(SS^*)^2$$

$$m_\sigma^2 = \alpha H^2 + m^2$$

R. Kallosh and A. Linde (2010)
R. Kallosh, A. Linde and T. Rube (2010)

Curvaton perturbations and non-Gaussianity

During inflation, the curvaton perturbations are produced.
Then these fluctuations are stretched, overlap with each other and eventually produce a classical curvaton field σ which looks relatively homogeneous in the observable part of the Universe, but may take different values in other parts.

These perturbations will match the COBE normalization of the spectrum for

$$r\frac{\delta\sigma}{\sigma} \sim 7 \times 10^{-5}$$

The prediction for the curvaton scenario is

$$f_{NL} = \frac{5}{4r}$$

$\Big\}$ f_{NL}

where $r \approx \left(\frac{\rho_\sigma}{\rho}\right)_{decay}$

$$-10 < f_{NL}^{obs} < 74$$

Seven-year WMAP data

E. Komatsu et al. (2010)

During inflation the long-wavelength distribution behaves
as a **nearly homogeneous classical field** in slow roll regime with:

$$3H\dot{\sigma} + m_\sigma^2 \sigma = 0$$

For the moment we assume a quadratic potential.

Each interval H^{-1} new fluctuations are generated:

$$\langle \delta\sigma^2 \rangle = \frac{H^2}{4\pi^2}$$

This effect increases the average squared of the classical field:

$$\frac{d\langle\sigma^2\rangle}{dt} = -\frac{2m_\sigma^2\langle\sigma^2\rangle}{3H} + \frac{H^3}{4\pi^2}$$

$$\frac{d\varphi}{dt} \simeq -\frac{V_{,\varphi}}{3H}$$

$$H^2 \simeq \frac{V}{3}$$

$$\Rightarrow \quad \boxed{\frac{d\langle\sigma^2\rangle}{d\varphi} = \frac{2m_\sigma^2\langle\sigma^2\rangle}{V_{,\varphi}} - \frac{V^2}{12\pi^2 V_{,\varphi}}}$$

Note that in different parts of the Universe σ might be smaller or bigger than $\langle\sigma^2(\varphi)\rangle$

Curvaton with $\alpha = 0$: $m_\sigma^2 = m^2$

$$\boxed{\varphi\sigma \lesssim 1} \quad \longrightarrow \quad \varphi_i \lesssim m^{-1/3}$$

$$\langle \sigma^2(\varphi) \rangle \simeq \frac{m^2 \varphi^2 \varphi_i^2}{96\pi^2}$$

$$\delta\sigma \sim \frac{H}{2\pi} = \frac{m\varphi}{2\pi\sqrt{6}}$$

$$\Rightarrow \quad \boxed{\frac{\delta\sigma}{\sigma} = \frac{2}{\varphi_i}}$$

Upper bound on φ_i to remain inside the region: $\varphi_i \simeq m^{-1/3}$

$$\longrightarrow \quad \frac{\delta\sigma}{\sigma} \sim m^{1/3}$$

For $m \sim 10^{-7}$ $\longrightarrow$ $\boxed{f_{NL} \sim 80}$

Curvaton with $\alpha = 0$: $m_\sigma^2 = m^2 + \frac{9}{2} H^2 \sigma^2$

$$\varphi\sigma \gtrsim 1$$

Solve the equation for $V = \frac{m^2\varphi^2}{2} + \frac{m^2\sigma^2}{2} + \frac{m^2\varphi^2\sigma^4}{16}$

$$\rightarrow \quad \frac{\delta\sigma}{\sigma} \sim 0.4 m^{1/3}$$

$m \sim 10^{-7}$ $f_{NL} \sim 30$

Curvaton with $m_\sigma^2 = \alpha H^2 + m^2$ and $0 < \alpha \ll 1$

$$\rightarrow \quad \frac{\delta\sigma}{\sigma} \simeq \sqrt{\frac{\alpha}{3}}$$

For $\alpha = 10^{-5} \rightarrow$ $\boxed{f_{NL} \sim 30}$

For $\alpha = 10^{-2} \rightarrow$ $\boxed{f_{NL} \sim 10^3}$!!!

Why is the result so sensitive to the parameter α ?

This parameter makes the mass of the curvaton field bigger than the mass of the inflaton: $m_\sigma^2 = \alpha H^2 + m^2$

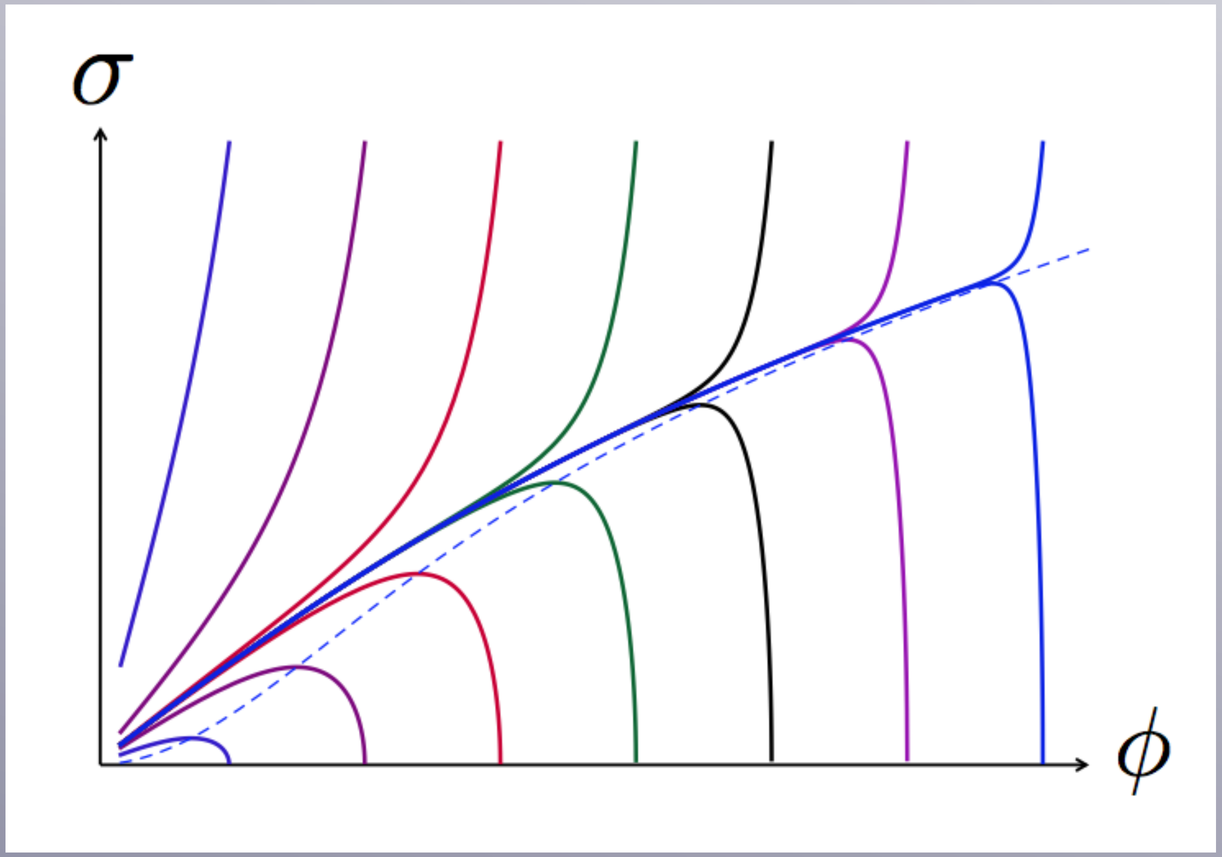
So the distribution of the curvaton shrinks fast while the inflaton rolls down.

Curvaton with $m_\sigma^2 = \alpha H^2 + m^2 + \frac{9}{2}H^2\sigma^2$ and $\alpha > 0$

$$V = \frac{m^2\varphi^2}{2} + \frac{m^2\sigma^2}{2} + \frac{m^2\varphi^2\sigma^4}{16} + \alpha\frac{m^2\varphi^2\sigma^2}{6}$$

There is no exact analytical solution.

If inflation lasts long enough, all solutions, **independently of the initial conditions**, converge at a certain **attractor trajectory**.



If inflation is long enough, the final results do not depend on the choice of the initial conditions for the curvaton field.

Conclusions

- ✶ Curvaton scenario implemented in the simplest supergravity realization of chaotic inflation.

- ✶ Discussion of observational consequences: non-Gaussianity
  - ➢ f_{NL} can be in the **observationally interesting range**

- ✶ If inflation is long enough, the average value of the non-Gaussianity parameter does not depend on initial conditions for the curvaton field.