Perturbations from an Inflationary Spectator Field

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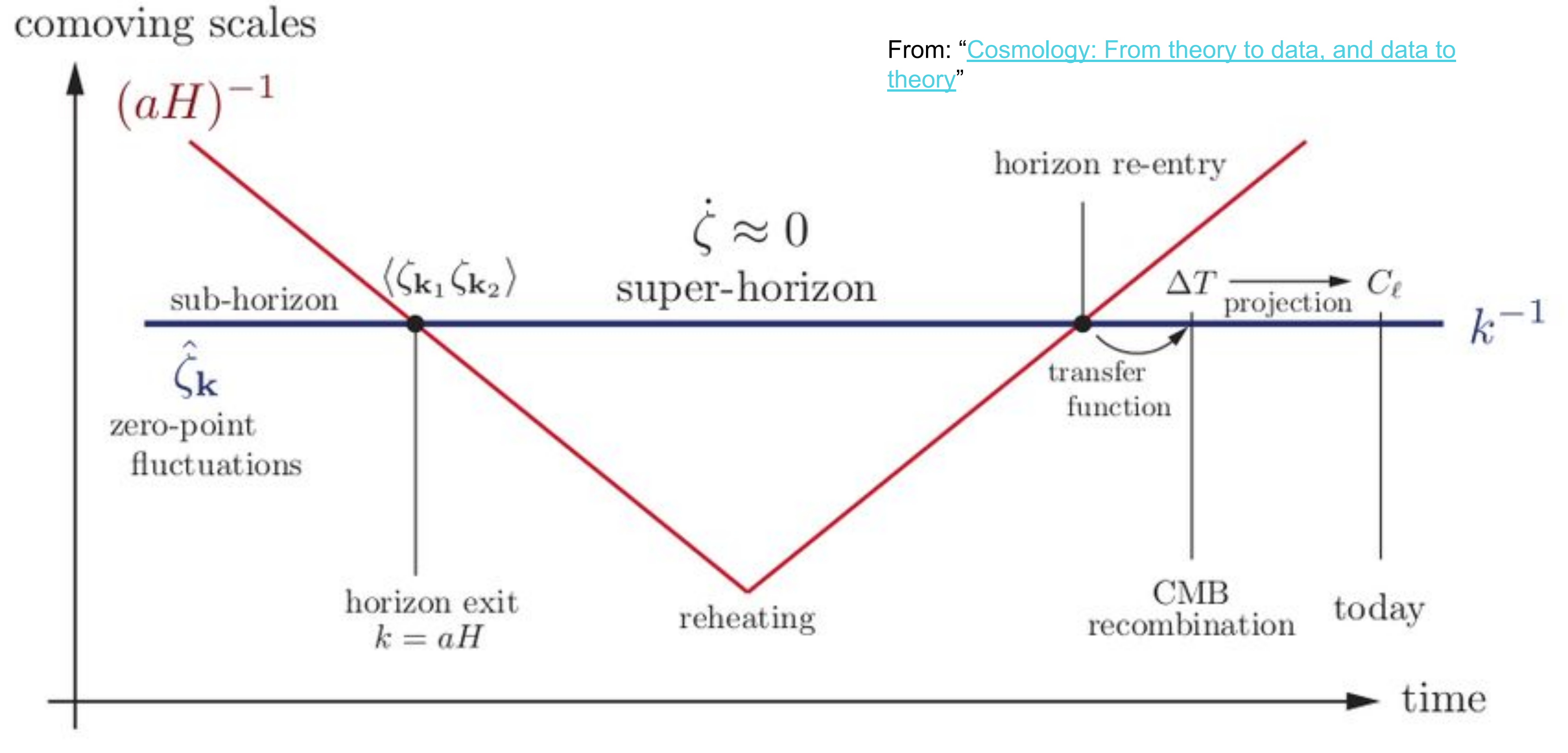
Inflation Review



From: "Cosmology: From theory to data, and data to theory"

Inflation Review

We moved on from inflation with it under siege:

-Quadratic Inflaton Potential all but ruled out

-Inflaton had to be heavier than Planck mass

-Planck data and others have shown evidence of *Non-Gaussianity*

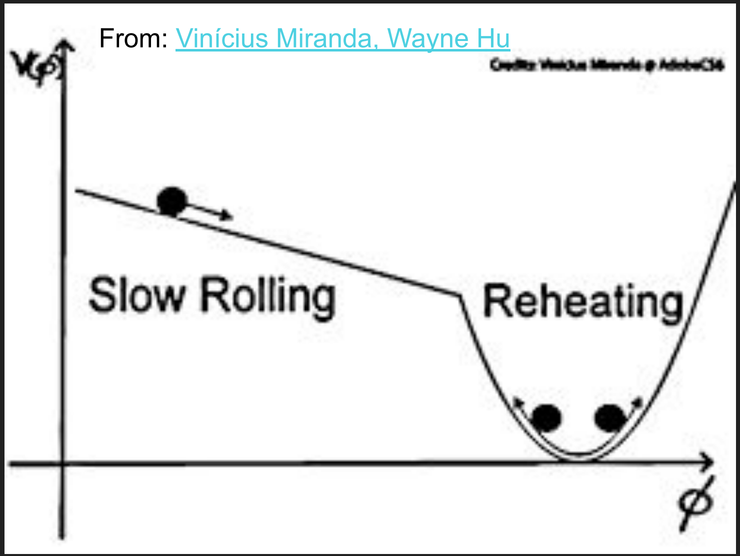
-Assumed Inflaton became radiation instantaneously

Inflation Review

Number of E Folds: $N = \ln \frac{a_i}{a_e}$

If step function reheating: $N_{\text{inf}} = \int_{t_\star}^{t_e} H dt$

If actual reheating: $N = \int_{t_\star}^{t_e} H dt + \int_{\rho_e}^{\rho_f} \frac{H}{\dot{\rho}} d\rho$



From: Vinícius Miranda, Wayne Hu

Light Scalar Fields we consider

Curvaton Field: $\sigma_c \longrightarrow \quad \zeta = \frac{1}{M_{\text{pl}}^2}\frac{V}{V_\phi}\delta\phi_\star + \frac{\partial Q}{\partial\sigma}\delta\sigma_\star$

$$\eta = M_{\text{pl}}^2 \frac{V_{\phi\phi}}{V} \qquad \epsilon = \frac{1}{2} M_{\text{pl}}^2 \left(\frac{V_\phi}{V}\right)^2$$

Moduli Field: σ_m

$$\begin{aligned} \dot{\rho}_\phi &= -3H\rho_\phi - \Gamma(\sigma_m)\rho_\phi \\ \dot{\rho}_\gamma &= -4H\rho_\gamma + \Gamma(\sigma_m)\rho_\phi \end{aligned}$$

Non-Gaussianity

Non-linearity parameters

$$N_a \equiv \frac{\partial N}{\partial \phi^a}$$

- Bispectrum

$$\frac{6}{5} f_{NL} = \frac{N_a N_b N^{ab}}{(N_c N^c)^2}$$

(Measured by Planck to be 2.7 ± 5.8)

- Trispectrum

$$\tau_{NL} = \frac{N_{ab} N^{ac} N^b N_c}{(N_d N^d)^3}$$

$$\frac{54}{25} g_{NL} = \frac{N_{abc} N^a N^b N^c}{(N_d N^d)^3}$$

Curvaton

- Scalar field that is present but subdominant during inflation
- Curvaton perturbations are independent from inflaton perturbations
- Different scenarios lead to different observables
  - How does the primordial value of σ_C compare to $m_{p\ell}$?
  - When does the curvaton decay?

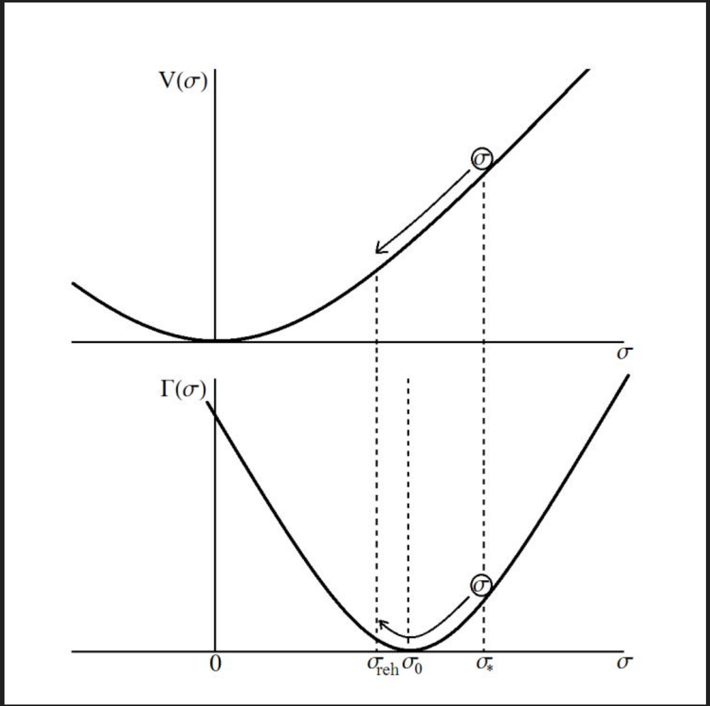
Curvaton

Three scenarios:

- Lighter field and later decay
  - Curvaton-domination after inflation, but not enough to drive a second inflation
- Lighter field and sooner decay
  - Curvaton never dominates, but plays a role in perturbations from inflation through reheating and into radiation-domination
- Primordial $\sigma_C > m_{pl}$
  - Curvaton-domination drives a second period of inflation

Moduli Fields

- Scalar field(s) that controls the decay rate of the inflaton
- Perturbations in the modulus field ⇒ Spatially-dependent reheating
- Modulated reheating models can source large effects on perturbations despite being much lighter than the Planck mass



From [2]

Effect of Spectator Fields on the primordial Power Spectrum and Spectral Indices

Recall that we defined the (dimensionless) perturbation power spectrum as

$$\mathcal{P}(k) \propto k^{n_s - 1}$$

With the spectral index

$$n_s = \frac{\mathrm{d} \ln \mathcal{P}}{\mathrm{d} \ln k}$$

and it's running defined as

$$\alpha \equiv \frac{\mathrm{d} n_s}{\mathrm{d} \ln k}$$

Effect of a Curvaton on the primordial Power Spectrum and Spectral Indices

- From [2], the introduction of a quadratic curvaton potential (uncorrelated with the inflaton) modifies the power spectrum of the perturbations.
- In turn, n_s is *lowered*, so that the spectrum gets *red-tilted* by having a curvaton. Furthermore, r and the running of n_s are also lowered.

Effect of a Moduli Field on the primordial Power Spectrum and Spectral Indices

- For the moduli scenario, the reheating power spectrum is dependent on the decay rate of the inflaton.
- However, n_s and the running of n_s are not affected by any dynamics of σ_m (following horizon crossing) [3].

Effect of a Curvaton on the Validity of Inflaton Models

- Current observations (of n_s, r, etc.) exclude multiple single-field (solo inflaton) models, such as quartic and higher order polynomial inflaton potentials (i.e. "Chaotic Inflation") [2].

- However, the addition of a curvaton to these inflaton scenarios can produce observational parameters that can match up to observations
- Some inflaton scenarios are hardly affected by the addition of a curvaton
  - E.g. a Quadratic Chaotic Inflation potential

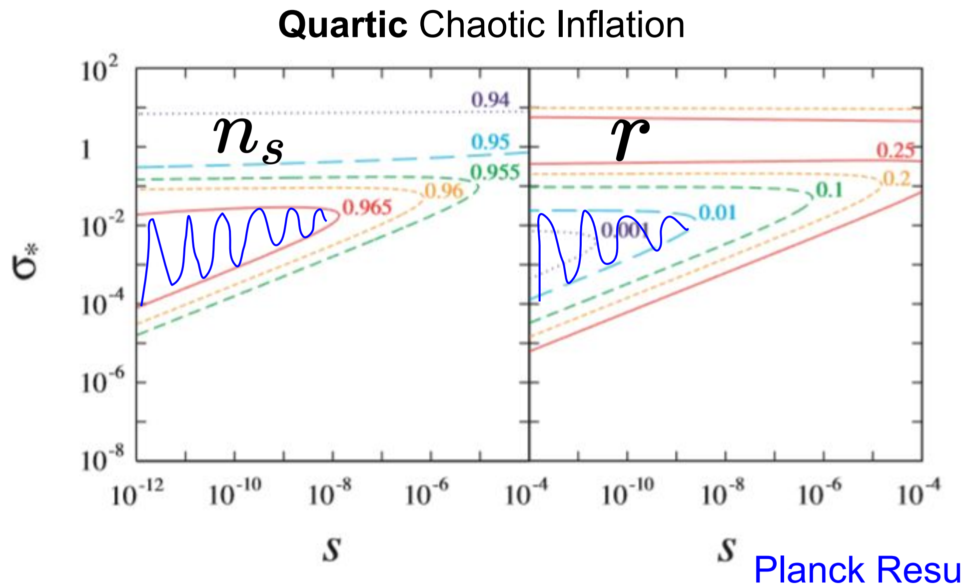
Effect on the Gaussianity of Observed Perturbations: Curvaton

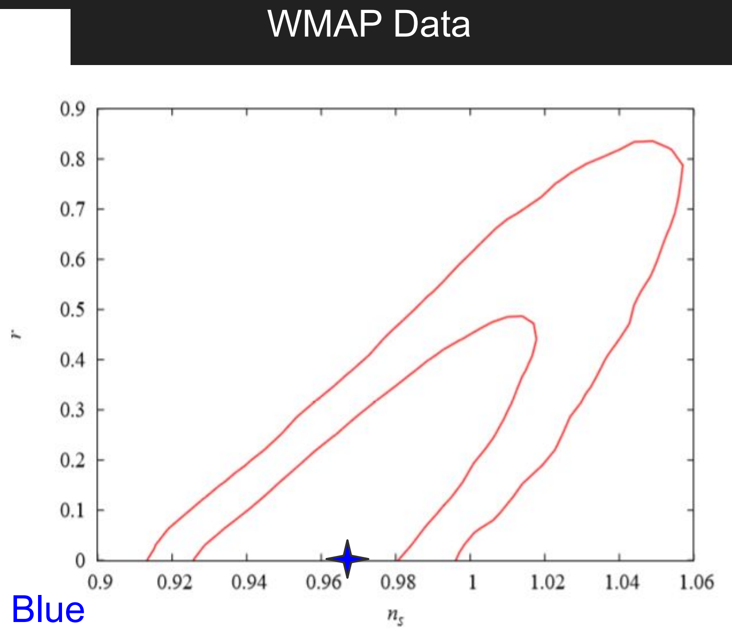
- Very large f_{NL} (from the bispectrum) can be produced in a mixed curvaton-inflaton scenario, even when the contribution of the curvaton to the overall perturbations is small.
- A small curvaton contribution can produce large trispectrum nonlinearity.

Effect on the Gaussianity of Observed Perturbations: Modulated Reheating

- f_{NL} can be of noticeable magnitude from the inclusion of a modulus field, even when the mass of the field is small compared to H, especially if the decay rate of the inflaton or the mass are rapidly changing.

Comparison to WMAP3 data [1]





Planck Results in Blue

$$s \equiv \frac{\Gamma_\sigma}{m_\sigma}$$ (These parameterize the curvaton)

References

1. Kazuhide Ichikawa et al. “Non-Gaussianity, Spectral Index and Tensor Modes in Mixed Inflaton and Curvaton Models”. In: (2008). arXiv:0802.4138.

2. Naoya Kobayashi, Takeshi Kobayashi, and Adrienne L. Erickcek. “Rolling in the Modulated Reheating Scenario”. In: (2013). arXiv:1308.4154.