Non-standard primordial fluctuations in LARGE volume inflation

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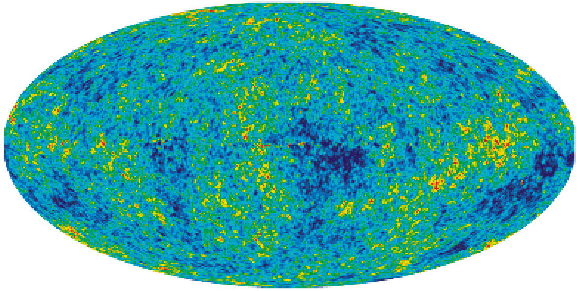
Based on: arXiv:1005.4840 [hep-th] (published in JHEP)
and work in preparation

with C. Burgess, M. Cicoli, M. Gómez-Reino, F. Quevedo, I. Zavala

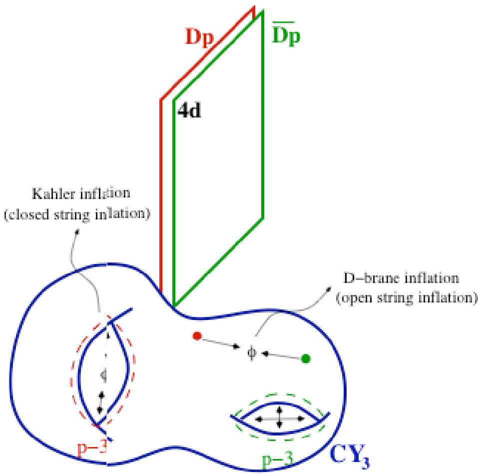
Inflation in String Theory

Inflation solves problems of Standard BB cosmology

and allows to understand CMB and LSS



Is it possible to realize it within String Theory?



- ▷ Embedding in fundamental theory allows to unify with particle physics models

  Calculate inflationary potential and couplings with SM

- ▷ Inflation usually very sensitive to its ultraviolet completion

  Dimension six, Planck suppressed contributions influence dynamics: η-problem

  Good theoretical control of underlying theory is necessary

- ▷ Connect parameters of string model with observable quantities

Light fields during inflation

- In **string inflation**, it is usually assumed that the inflaton(s) is the last light modulus to roll towards the minimum
- But it is **not** necessary. Other moduli can remain light, influencing generation of curvature perturbations, without taking part to inflation

Example I: Curvaton

[Mollerach, Linde-Mukhanov, Lyth-Wands, Enqvist-Sloth, Moroi-Takahashi]

Example II: Modulated reheating

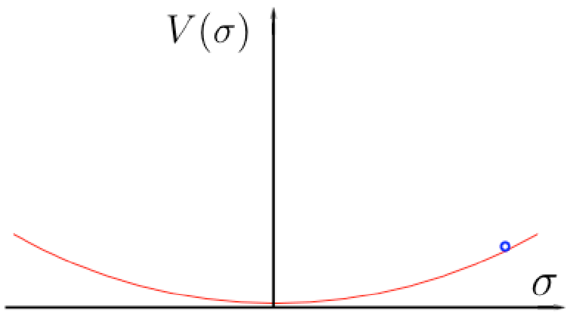
[Dvali-Gruzinov-Zaldarriaga, Kofman]

Light fields during inflation

Example I: Curvaton

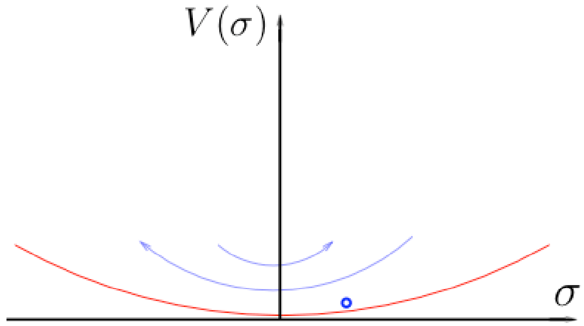
- Besides inflaton φ, there is a second light field σ, with $\rho_\sigma \ll \rho_\varphi$, quadratic potential, and $m_\sigma \ll m_\varphi$. Curvature fluctuations ζ_ϕ due to inflaton negligible

- Being **very light** during inflation, σ's homogeneous value is **almost frozen**. But it develops quantum fluctuations with amplitude $\delta\sigma \simeq H/2\pi$



- After inflation, inflaton energy gets **converted** into SM dof, e.g. γ. Universe initially dominated by radiation $\rho_\gamma \propto 1/a^4$

- When $H \simeq m_\sigma$, curvaton starts to oscillate around its minimum. Its energy density $\rho_\sigma \propto 1/a^3$.



- When $H \simeq \Gamma_\sigma$ curvaton decays; let its energy density $\rho_\sigma = \Omega \rho_{tot}$.

  Isocurvature σ perts get converted into **adiabatic, curvature perts** ζ

Light fields during inflation

Advantages

- ▷ **More freedom** with inflaton potential. Easier to control
- ▷ **Natural** to realize within string theory: many light moduli around
- ▷ Distinctive **observational consequences**
  - Negligible gravitational waves
  - Potentially **large non-Gaussianity**: $f_{\rm NL} = \frac{5}{4\Omega}$

Example II: Modulated reheating

- Suppose that a **light field** σ alters the decay rate of inflaton to SM particles,

  e.g. via $\lambda(\sigma)\,\varphi\, qq$

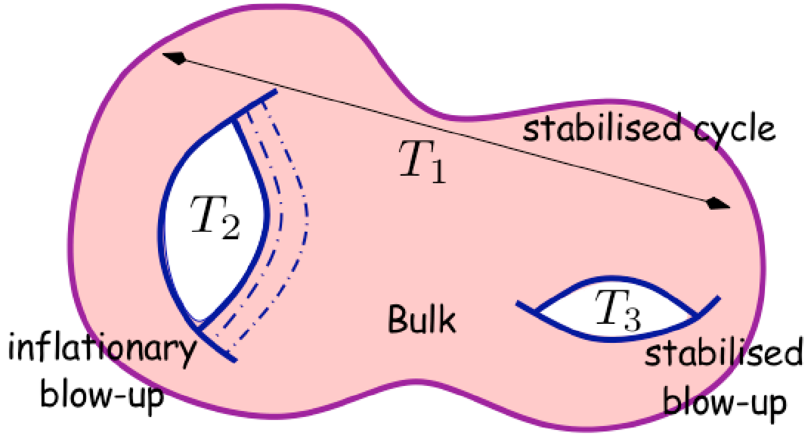
- Reheating starts at different times in different places. This affects curv perts

$$\zeta \propto \frac{\delta\Gamma}{\Gamma} \propto \frac{\delta\lambda}{\lambda}$$

A concrete framework in string theory

- IIB compactification within LARGE volume scenarios. Moduli stabilized by interplay of fluxes plus non-perturbative and α' effects.
  Volume $\mathcal{V}$ of the compact manifold exp LARGE [Balasubramanian et al, Conlon et al.]

- Two promising models discussed so far
  - **Kahler modulus inflation**
    Swiss-cheese CY, inflaton is size of a small blow-up mode [Conlon-Quevedo]
  - **Fiber inflation**
    CY is a K3 fiber over CP^1 base, inflaton is fibration modulus [Cicoli et al]



- What they offer
  - η-problem avoided due to approx no-scale structure of potential [Copeland et al]
    Corrections organized in **expansion** in terms of inverse powers of $\mathcal{V}$
  - Introduce $D7$-branes with visible matter.
    Moduli **couplings** to matter are explicitly computable.

Idea: put **together** the two scenarios to realize a natural **curvaton model** characterized by **large non-Gaussianities**

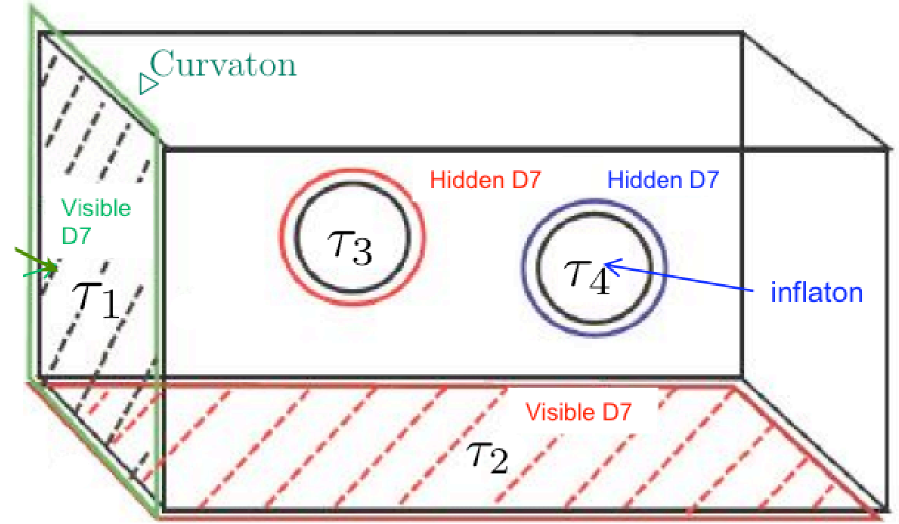
What we need:

Two moduli for inflaton plus curvaton, plus **one** stable modulus corresponding to the overall volume. We need also **one** more modulus to assist stabilization process

1) A fiber modulus τ_1, the curvaton. Wrapped by stack D7-branes (visible sector lives here)

2) A base modulus τ_2, overall volume. Heavy during inflation, thanks to non-perturbative effects

3) A blow-up mode τ_3, assists volume stabilization. Heavy during inflation



4) A second blow-up mode τ_4, the inflaton.
Potential generated by non-pert effects, it's light during inflation being displaced from its minimum

Ingredients

- Volume can be written $$\mathcal{V} = \alpha\left(\sqrt{\tau_1}\tau_2 - \gamma_3\tau_3^{3/2} - \gamma_4\tau_4^{3/2}\right)$$

- Kähler potential (including α' corrections) $$K = -2\ln\left[\mathcal{V} + \frac{\xi}{2g_s^{3/2}}\right]$$

- Superpotential $$W = W_0 + A_3 e^{-a_3 T_3} + A_4 e^{-a_4 T_4}$$

- Scalar potential so far

$$V = \frac{g_s}{8\pi}\left[\frac{3\,\beta\,\xi\,W_0}{4\,g_s^{3/2}\mathcal{V}^3} - 4\sum_{i=3}^{4} W_0\,a_i A_i\left(\frac{\tau_i}{\mathcal{V}^2}\right)e^{-a_i\tau_i} + \sum_{i=1}^{4}\frac{8\,a_i^2 A_i^2}{3\,\alpha\gamma_i}\left(\frac{\sqrt{\tau_i}}{\mathcal{V}}\right)e^{-2a_i\tau_i}\right]$$

Fixes τ_3, τ_4 plus the combination $\mathcal{V} \simeq \alpha\sqrt{\tau_1}\tau_2$

$$J = \sum_{i=3}^{4}\frac{\gamma_i}{a_i^{3/2}}$$

$$a_i\langle\tau_i\rangle = \left(\frac{\xi}{2\,g_s^{2/3}\alpha\,J}\right)^{2/3}, \qquad \langle\mathcal{V}\rangle = \left(\frac{3\,\alpha\,\gamma_i}{4\,a_i\,A_i}\right)W_0\sqrt{\langle\tau_i\rangle}e^{a_i\langle\tau_i\rangle} \qquad i = 3,4$$

- Adding subleading string loop corrections to K one gets potential for τ_1

$$\delta V = \left(\frac{A}{\tau_1^2} - \frac{B}{\mathcal{V}\sqrt{\tau_1}} + \frac{C\tau_1}{\mathcal{V}^2}\right)\frac{g_s\,W_0^2}{8\pi\,\mathcal{V}^2}$$

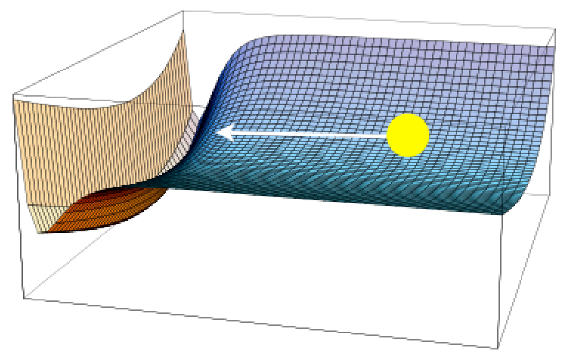
Inflation

- During inflation, $\mathcal{V}$ and τ_3 are **heavy** and sit on their minima.
  τ_1 and τ_4 are **light** and evolve independently.

- τ_4 is the **inflaton** field. When displaced from its minimum, the potential is

$$V(\tau_4) \simeq V_0 - \frac{g_s W_0 A_4\, a_4 \tau_4}{2\pi \mathcal{V}^2}\, e^{-a_4\tau_4}$$

Hubble parameter $\quad H^2 = \frac{c_H M_{Pl}^2}{\mathcal{V}^3}$



- Say $a_4\tau_4 \sim (2+n)\ln\mathcal{V}$. **Field masses** scale with $\mathcal{V}$ as

$$m_{\tau_3}^2 \sim \frac{M_{Pl}^2}{\mathcal{V}^2} \quad , \quad m_{\mathcal{V}}^2 \sim \frac{M_{Pl}^2}{\mathcal{V}^3} \quad \Rightarrow \quad \textbf{heavy}$$

$$m_{\tau_4}^2 = \frac{c_{\tau_4} M_{Pl}^2}{\mathcal{V}^{3+n}} \quad , \quad m_{\tau_1}^2 \sim \frac{c_{\tau_1} M_{Pl}^2}{\mathcal{V}^{10/3}} \quad \Rightarrow \quad \textbf{light}$$

- 60 **e-folds** of inflation can be easily obtained along τ_4 direction.

- No surprise that τ_1 **remains light**: potential controlled by string loops.

Realization of curvaton mechanism

- τ_1 potential $V(\tau_1) = \frac{1}{2} m_{\tau_1}^2 \tau_1^2$ with $m_{\tau_1}^2 = \frac{c_{\tau_1} M_{Pl}^2}{\mathcal{V}^{10/3}} \ll H^2 = \frac{c_H M_{Pl}^2}{\mathcal{V}^3}$

  No direct couplings with inflaton field τ_4. τ_1 is good curvaton candidate!

- Wrap $D7$ on τ_1 cycle. Couplings between τ-moduli and wv gauge field $F_{\mu\nu}$ can be calculated: $\lambda \frac{\tau_i}{M_{Pl}} F_{\mu\nu} F_{\mu\nu}$

  [Conlon-Quevedo, Cicoli-Mazumdar]

	τ_1	τ_2	$\tau_i,\ \forall\, i = 3, 4$
$F_{\mu\nu}F^{\mu\nu}$	$\frac{2}{\sqrt{3}\, M_p}$	$\sqrt{\frac{2}{3}}\, \frac{1}{M_p}$	$\frac{3\,(\ln \mathcal{V})^{\frac{3}{4}}}{2\, a_i\, \mathcal{V}^{1/2}\, M_p}$

- Using formula for decay rate of modulus τ_i in gauge boson g, $\Gamma_{\tau_i \to gg} = \frac{N_g \lambda^2 m_{\tau_i}^2}{64\pi}$,

$$\Gamma_{\tau_1 \to gg} \simeq \frac{M_p}{\mathcal{V}^5}, \qquad \Gamma_{\tau_2 \to gg} \simeq \frac{M_p}{\mathcal{V}^{9/2}}, \qquad \Gamma_{\tau_j \to gg} \simeq \frac{M_p}{\mathcal{V}^4}, \quad \forall\, j = 3, 4.$$

  Inflaton τ_4 has the largest decay rate. It decays earlier than curvaton τ_1

- After inflation ends, and well before nucleosynthesis, curvaton decays.

  Its relative energy density $\Omega = \frac{\rho_{\tau_1}}{\rho_{Tot}} \propto \frac{1}{\mathcal{V}^{2/3}}$

Realization of curvaton mechanism

- Adiabatic curvature perturbation given by formula

$$\zeta \quad = \quad \frac{\Omega}{3}\frac{\delta\rho_{\tau_1}}{\rho_{\tau_1}} \quad = \quad \frac{2\,\Omega}{3}\frac{\delta\tau_1}{\tau_1} + \frac{\Omega}{3}\frac{\delta\tau_1^2}{\tau_1^2} \quad = \quad \zeta_G + \frac{3}{5} f_{\rm NL}\,\zeta_G^2$$

Identifying $\zeta_G = \frac{2\,\Omega}{3}\frac{\delta\tau_1}{\tau_1}$, $f_{\rm NL} = \frac{5}{4\Omega}$ of local form

- COBE normalization for power spectrum gives constraints on parameters.

Nevertheless $f_{\rm NL}$ can be large:

$$f_{\rm NL} = 10^5 \frac{\left(\beta\xi W_0^2\right)^{1/3}}{g_s^{1/6}\,\mathcal{V}}$$

$\mathcal{V}$	a_4	ξ	g_s	W_0	α	A_4	γ_4
10^3	$\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{100}$	$\frac{1}{10}$	6	$\frac{1}{10}$	20

$$\Rightarrow \quad f_{NL} \sim 57$$

- Parameters can be chosen to get successful inflation and large $f_{\rm NL}$

Challenge: find explicit set-ups characterized by these numbers

Outlook

▷ I presented a **curvaton model** in the context of **LARGE volume inflation**.

- It enjoys nice features of models of inflation in this framework
- Moreover, it can lead to **large** $f_{\rm NL}$

▷ Other set-ups can be obtained along these lines

- With additional small cycles, suitably displaced from their minima, models of **modulated reheating** can be realized [in preparation]
- Non only $f_{\rm NL}$, but also non-Gaussian parameter $g_{\rm NL}$ **can be large**

$$\Downarrow$$

Testable with Planck satellite

▷ Once the most interesting configurations are determined,
challenge: find explicit set-ups characterized by corresponding parameters