Stringy Origins of Cosmic Structure

The D-brane Vector Curvaton

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Outline

1. Motivation
   - Inflation in String Theory
   - The Vector Curvaton Paradigm
2. D3-brane Vector Curvaton
3. D7-brane Vector Curvaton
4. Conclusions

Fields in Type IIB early universe models

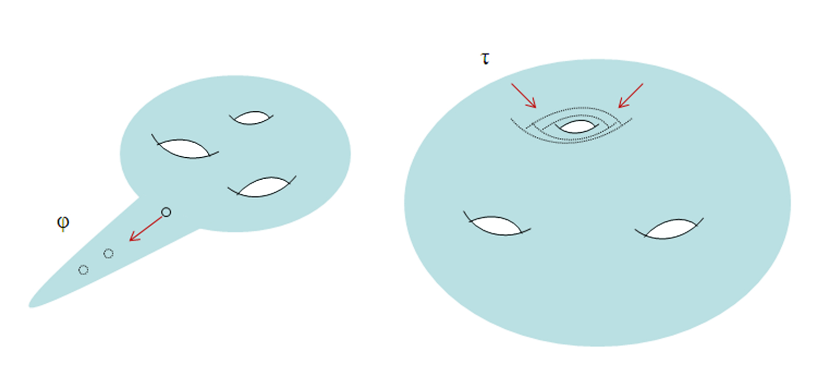

Figure: Open string inflation in a warped throat (left), closed string inflation in the Large volume scenario (right)

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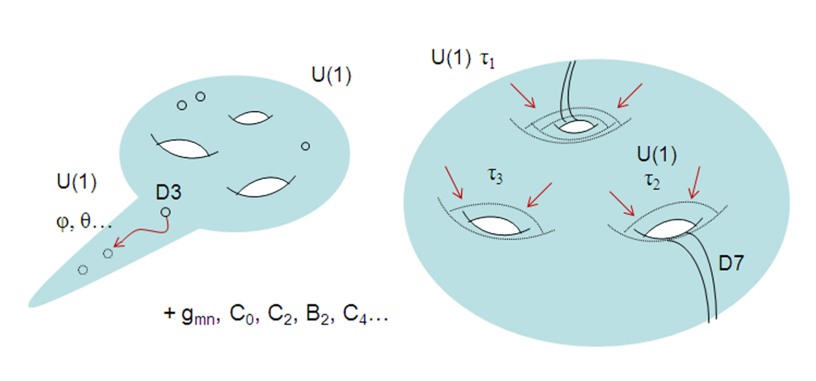

Figure: Open string inflation in a warped throat (left), closed string inflation in the Large volume scenario (right)

D-brane vector fields

- The U(1) vector field can obtain a Stückelberg mass via a coupling to a bulk 2-form field
- It may also couple to various scalars in the theory via its gauge kinetic function
- Can these massive vector fields impact the cosmology of the early universe?

Features of the Curvature Perturbation ζ

Cosmic inflation explains the appearance of ζ, which gives the initial condition for structure growth, by the process of gravitational particle production. The power spectrum $\mathcal{P}_\zeta$ is largely

- Scale Invariant
- Gaussian
- Statistically Homogeneous
- Statistically Isotropic

But notable deviations are allowed by the data. If a vector field contributes to ζ, statistical anisotropy would be generic.

The Vector Curvaton Paradigm[1] has demonstrated that:

- A massive vector field can affect ζ via undergoing particle production during inflation.
- At a later time the vector field will oscillate and decay, imprinting its spectrum.
- The vector field must be light while the scales exit the horizon such that its vacuum fluctuations may stretch ($M \ll H$).
- For a vector field with a mass m and gauge kinetic function f that are modulated by the scalars, in order to produce a scale invariant spectrum we also require:

$$f \propto a^{-1\pm 3}, \qquad m \propto a$$

where $a(t)$ is the cosmic scale factor.

[1] Dimopoulos 2008, Dimopoulos, Karciauskas, Wagstaff 2010

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We consider the vector field on a stationary or moving D3-brane, where the vector field couples to the bulk field C_2[2]. We aim to explore the possibilities for a stringy vector curvaton, in particular the observational features. We compute f and m:

$$f = \gamma(\varphi, \dot{\varphi}, ..)e^{-\phi}, \quad m^2 \propto \frac{e^{-\phi}}{\mathcal{V}_6}, \quad M \equiv \frac{m}{\sqrt{f}}$$

- These quantities depend on the scalars: φ (the inflaton in single or multifield scenarios), ϕ (the dilaton)
- The dilaton appears with the right powers in f and m for scale invariance assuming $e^{-\phi} \propto a^2$ and $M \ll H$ while the scales leave the horizon
- The inflaton may add a small degree of scale dependence

[2] Dimopoulos, DW, Zavala 2011

We compute the power spectrum for each component:

$$\mathcal{P}_{L,R} = \left(\frac{H}{2\pi}\right)^2, \;\; \mathcal{P}_{||} = 9\left(\frac{H}{M}\right)^2\left(\frac{H}{2\pi}\right)^2$$

$$M \ll H \Longrightarrow \mathcal{P}_{L,R} \ll \mathcal{P}_{||}$$

This can be quantified in the power spectrum of the curvature perturbation $\mathcal{P}_\zeta$ by the statistical anisotropy parameter g

$$g \propto \frac{\mathcal{P}_{L,R} - \mathcal{P}_{||}}{\mathcal{P}_\zeta^{iso}} \sim 0.1, \;\; 0.02 \leq g \leq 0.3$$

For the non-linearity parameter f_{NL} and its anisotropy $\mathcal{G}$ we obtain

$$||f_{NL}^{eq}|| \sim 10^2, \;\; \mathcal{G} = \frac{1}{8}\left(\frac{3H}{M}\right)^4 \gg 1, \;\; -214 < f_{NL}^{eq} < 266$$

Towards Model-Building

The D3-brane vector curvaton scenario encapsulates neatly the principle of a stringy vector curvaton, and, while not realistic, will serve as a starting point for model-building.

- Compactifying with $O3/O7$-planes rather than $O5/O9$-planes eliminates C_2 from the spectrum.
- $e^{-\phi} \propto a^2$ requires a linear potential and is therefore hard to realise.

In a concrete scenario one could consider branes of higher dimensionality, or a different mass generation mechanism (Higgs mechanism). The brane would need to be moving in order to give rise to effective time-dependence in the dilaton.

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We consider the vector field on a D7-brane wrapping a compact 4-cycle with Kähler modulus τ. We compute f and m:

- The gauge kinetic function $f \propto \tau$
- For the mass, the 2-form descends from C_4. For certain geometries we found that $m^2 \propto \frac{M_P}{\sqrt{\tau}\mathcal{V}}$
- In this case, if $\tau \propto a^{-4}$, then $m \propto a$ and we may obtain scale invariant spectra for all components of the D7-brane vector curvaton, as long as $M \ll H$ while the scales exit the horizon.

Kähler moduli inflation[3] is an example of slow-roll inflation, where the potential for the inflaton is exponentially flat. The slow-roll parameter ϵ quantifies the flatness of the potential V, and inflation is realised when $\epsilon \ll 1$.

$$\epsilon = \frac{M_P^2}{2}\left(\frac{V'}{V}\right)^2$$

For Kähler moduli inflation, $\epsilon < 10^{-12}$ for natural values of the parameters.

[3] Conlon, Quevedo 2005

Assuming that the inflaton (Kähler modulus) starts rolling at $\tau = nM_P$, it can be shown numerically that $f \propto a^{-4}$, $m \propto a$ may be realised during slow-roll inflation in two regimes[4]:

- $\frac{\sqrt{2\epsilon}}{4} < n$ (Standard Slow Roll Regime)
- $\frac{\sqrt{\epsilon}}{2\sqrt{2}} > n$ (Vector Backreaction Regime)

We require $\tau \propto a^{-4}$ for up to 10 efolds (the cosmological scales), which corresponds to a large field range, but still subPlanckian.

[4] Dimopoulos, Wagstaff 2010

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Conclusions and Outlook

- We have explored how the presence of several light fields in Type IIB models of inflation can lead to new features
- To demonstrate the possibilities, we considered a D3-brane vector curvaton scenario in open string inflation and showed that distinctive features arise in the spectrum and bispectrum of the curvature perturbation
- We then discussed a possible concrete model: the D7-brane vector curvaton in closed string inflation
- These signatures will be testable in the very near future as the first observations from the Planck satellite will be made available soon.

Thank you