

Multifield Cosmology in Large Volume Scenarios

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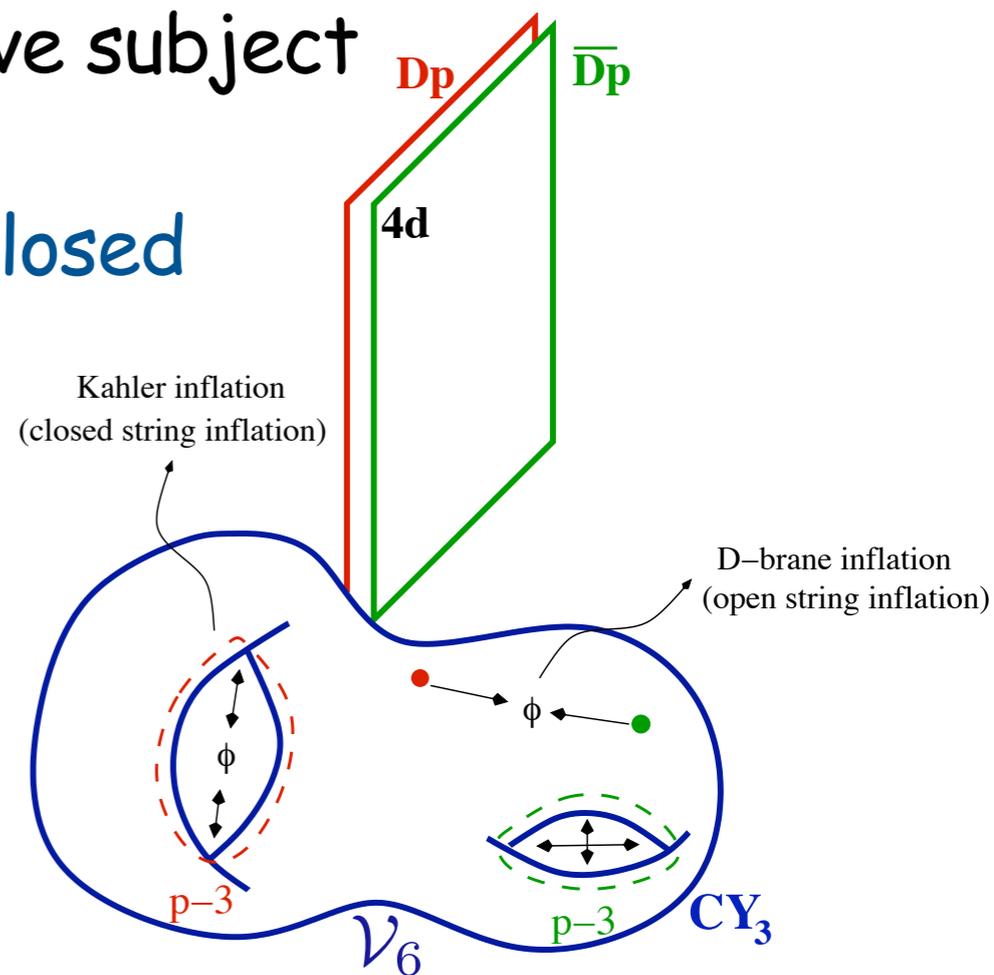
with

C.P.Burgess, M.Cicoli, M.Gómez-Reino, F.Quevedo, G.Tasinato
JHEP1008(2010)045 [arXiv:1005.484]

Motivation

String theory inflation has become a very active subject in the last years. Here, inflaton finds a natural **geometric interpretation** in terms of **open or closed string moduli**:

- open string modulus: **D-brane inflation** (brane position/WL)
- closed string modulus (geometric moduli, e.g. **Kähler inflation**)



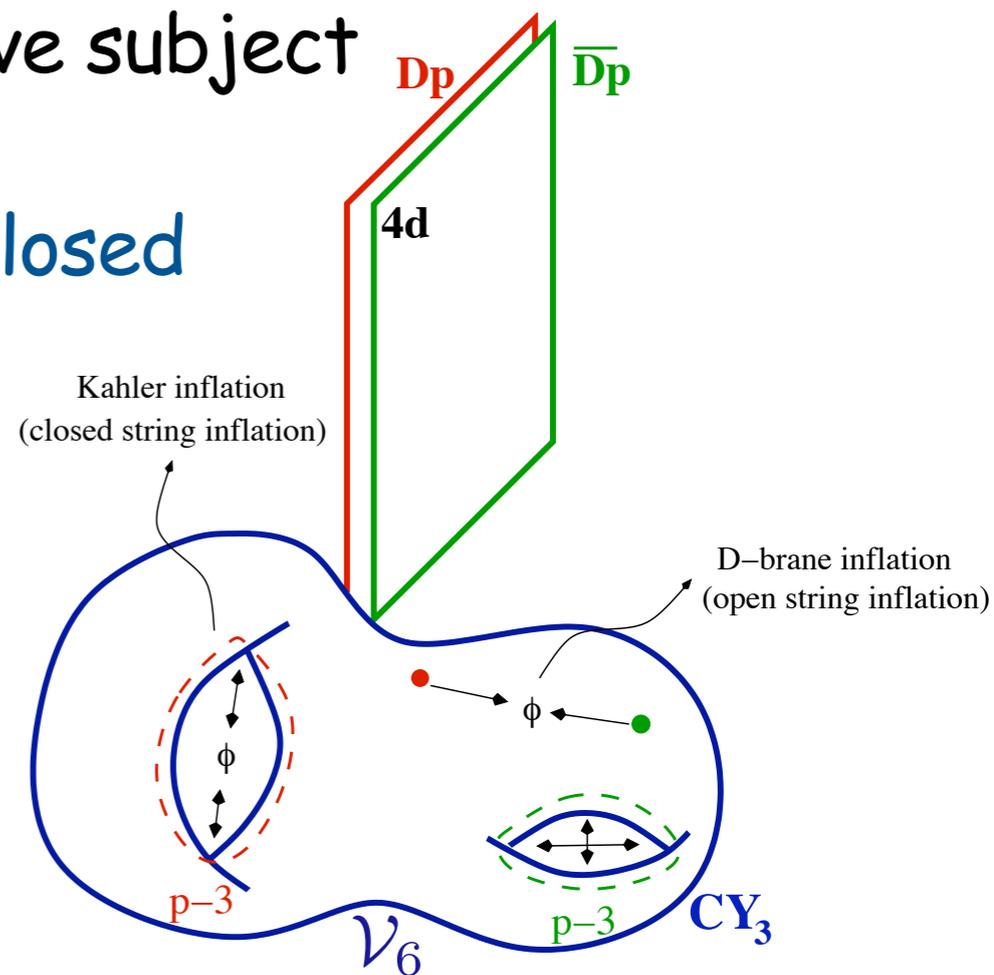
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- **negligible tensor modes** (scalar to tensor ratio $r \ll 1$)
- **nearly Gaussian spectrum** ($f_{NL} \sim 0$)

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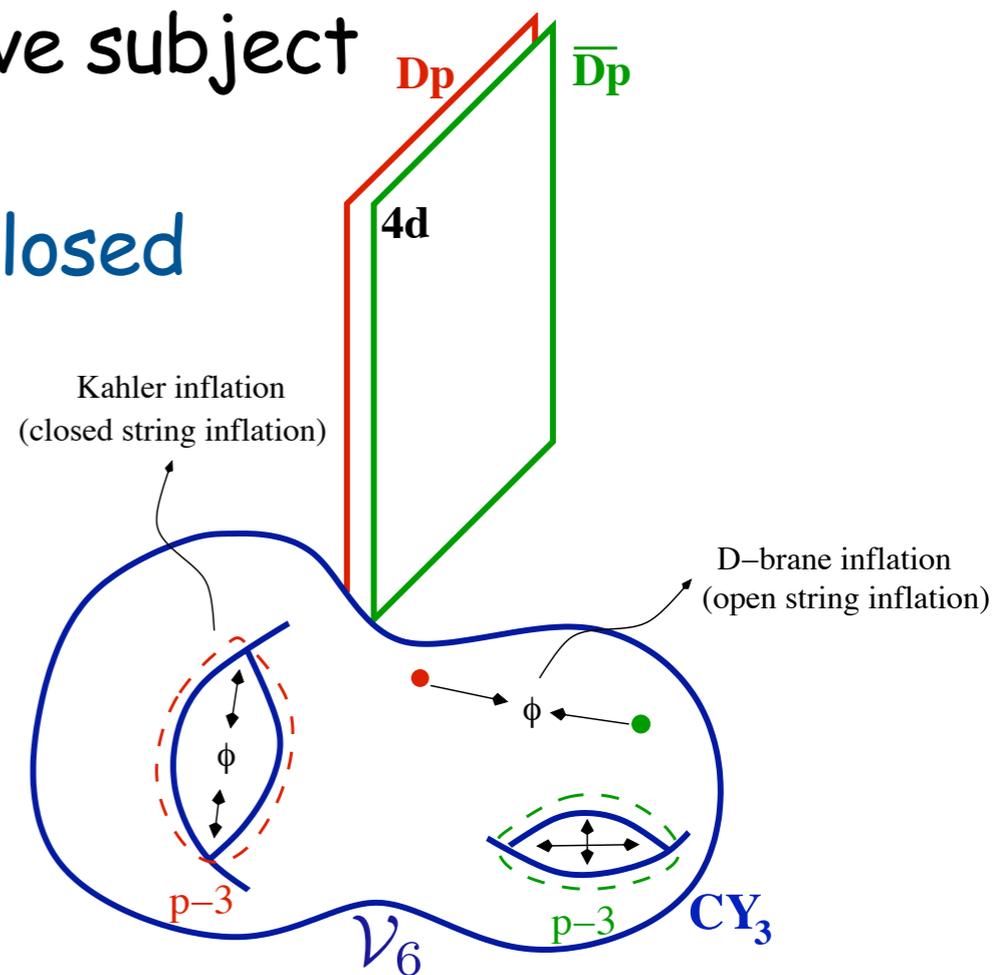
Is single field generic? What are implications of multifield dynamics?

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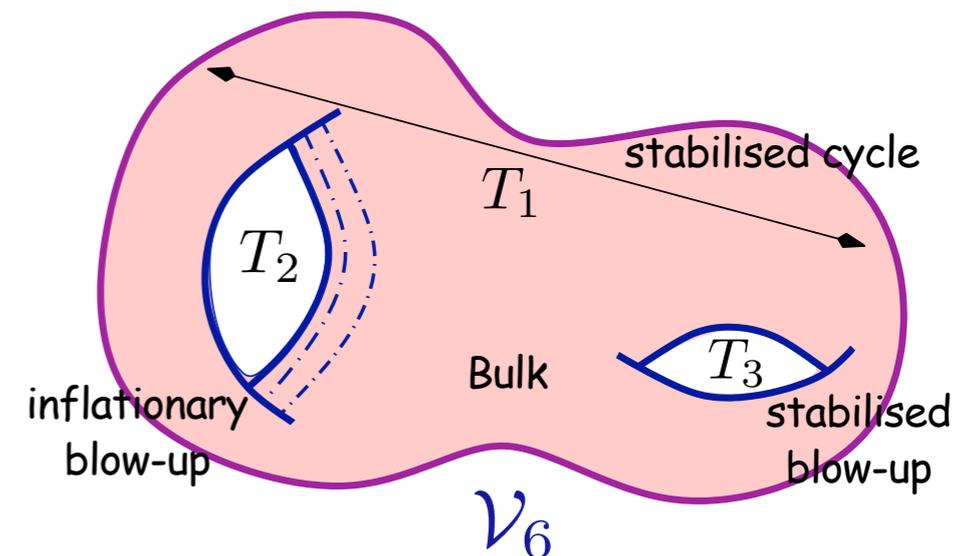
Kähler moduli cosmology

Study these questions in concrete string set-up: **type IIB LARGE Volume (LV) flux compactifications**. [Balasubramanian et al. Conlon et al. '05]

Generically several moduli are involved => requires study of **multifield cosmological evolution**.

Two (single field) Kähler inflationary scenarios have been studied:

- **Blow-up Inflation** [Conlon-Quevedo, '05]
(small cycle)
- **Fiber Inflation** [Cicoli-Burgess-Quevedo, '08]
(large cycle)



Combine these two models to study multifield cosmology in **LARGE Volume** framework, in a natural realisation of curvaton scenario to generate the density perturbations in non-standard fashion

Is it possible to obtain large non-Gaussianities??

The set up

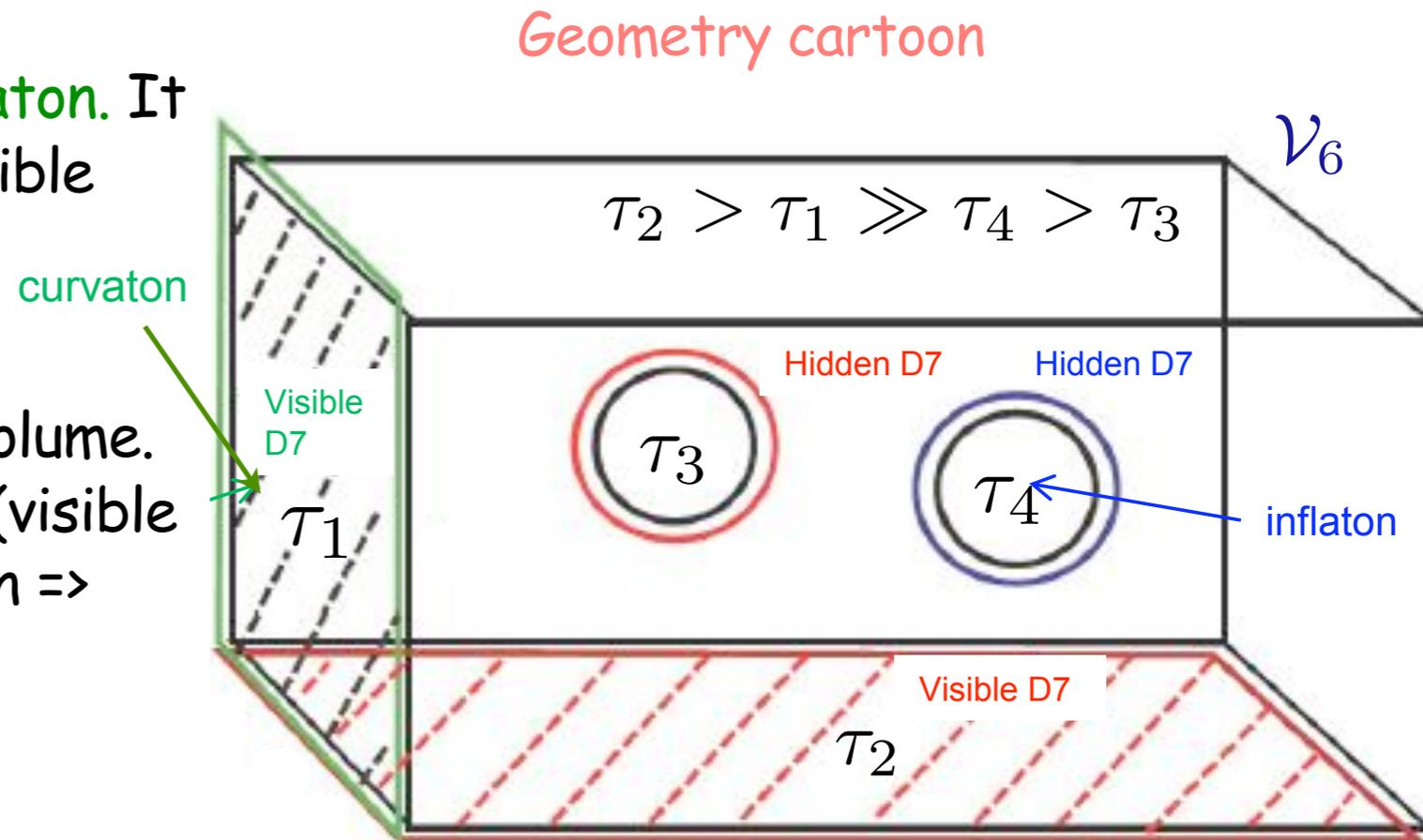
String theory compactification with minimal field content: CY_3 with $K3$ fibration controlled by 2 large 4-cycles (τ_1, τ_2) together with 2 small 4-cycles, or blow-up modes (τ_3, τ_4), such that:

i) A **fiber modulus** τ_1 : plays role of **curvaton**. It is wrapped by a stack of D7-branes (visible Standard Model sector lives here).

ii) A **base modulus** τ_2 : controls overall volume. It is wrapped by a stack of D7-branes (visible sector also here). Heavy during inflation \Rightarrow remains at minimum during cosmological evolution.

iii) A **blow-up mode** τ_3 : assists volume stabilisation. Non-perturbative generated potential via gaugino condensation on hidden sector D7-branes. Heavy during inflation \Rightarrow remains at minimum during cosmological evolution.

iv) Second **blow-up mode** τ_4 : plays the role of **inflaton** as in CQ. Potential generated via gaugino condensation on hidden sector D7-branes.



Scalar potential ingredients (4D SUGRA)

Scalar potential can be computed from

$$V = e^K \left(K^{A\bar{B}} D_A W D_{\bar{B}} \bar{W} - 3|W|^2 \right)$$

where Kähler potential (with α' corrections):

$$K = -2 \ln \left[\mathcal{V} + \frac{\xi}{2 g_s^{3/2}} \right];$$

$$\alpha' = \ell_s^2$$

$$\xi = \frac{(h_{1,2} - h_{1,1})\zeta(3)}{(2\pi)^3} > 0$$

and the superpotential is:

$$W \simeq W_0 + A_3 e^{-a_3 T_3} + A_4 e^{-a_4 T_4}$$

$$a_i = 2\pi/N_i$$

Moreover, compact 6D volume can be written as

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

Regime of interest: $\tau_2 > \tau_1 \gg \tau_4 > \tau_3$

Parameters of model: $(\alpha, \gamma_i, \xi, W_0, A_i, a_i)$

Scalar potential

Scalar potential including subleading loop corrections to Kähler potential is:

$$V = \frac{g_s}{8\pi} \left[\frac{3\beta\xi W_0}{4g_s^{3/2}\mathcal{V}^3} - 4 \sum_{i=3}^4 W_0 a_i A_i \left(\frac{\tau_i}{\mathcal{V}^2} \right) e^{-a_i \tau_i} + \sum_{i=1}^4 \frac{8 a_i^2 A_i^2}{3\alpha\gamma_i} \left(\frac{\sqrt{\tau_i}}{\mathcal{V}} \right) e^{-2a_i \tau_i} \right] \\ + \frac{g_s W_0^2}{8\pi\mathcal{V}^2} \left(\frac{A}{\tau_1^2} - \frac{B}{\mathcal{V}\sqrt{\tau_1}} + \frac{C\tau_1}{\mathcal{V}^2} \right) \quad B > 0$$

First term fixes (τ_3, τ_4) and the volume $\mathcal{V} \simeq \alpha\sqrt{\tau_1}\tau_2$ at:

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

Second term fixes second combination of (τ_1, τ_2) at

$$\langle \tau_1 \rangle \simeq \left(\frac{4A\mathcal{V}}{B} \right)^{2/3}$$

Cosmological evolution

During inflationary evolution, (ϕ_3, χ_2) are heavy $\Rightarrow (\mathcal{V}, \tau_3)$ sit at their minima while χ_1 and ϕ_4 (τ_1, τ_4) are light and evolve almost independently.

The potential during inflation is $V(\phi_4, \chi_1) = V_{inf}(\phi_4) + V_{cur}(\chi_1)$

Volume dependent mass spectrum during inflation:

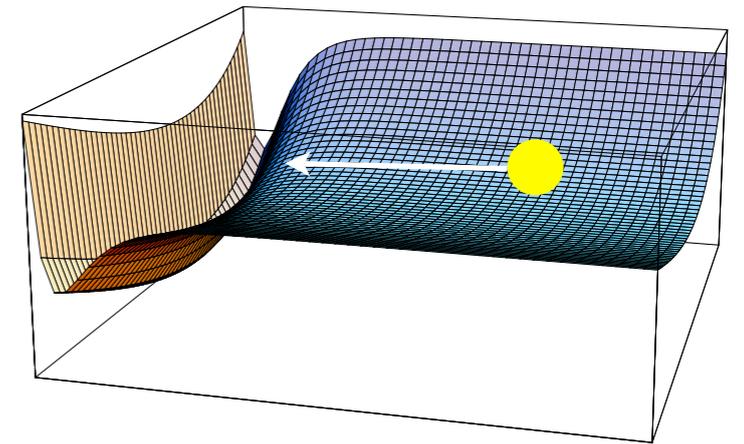
$$H^2 \sim \frac{M_p^2}{\mathcal{V}^3}$$

$$m_{\phi_3}^2 \sim \frac{M_p^2}{\mathcal{V}^2}, \quad m_{\chi_2}^2 \sim \frac{M_p^2}{\mathcal{V}^3} \quad \Rightarrow \quad \text{heavy!}$$

$$m_{\phi_4}^2 \sim \frac{g_s W_0^2}{4\pi} \frac{M_p^2}{\mathcal{V}^{3+n}}, \quad m_{\chi_1}^2 \sim \frac{g_s C_t W_0^2}{4\pi} \frac{M_p^2}{\mathcal{V}^{10/3}} \quad n > 0$$

Inflaton potential: [Conlon-Quevedo '05]

$$V_{inf}(\phi_4) \simeq V_0 - \frac{g_s W_0 a_4 A_4}{2\pi \mathcal{V}^2} \left(\frac{3\mathcal{V}}{4\alpha\gamma_4} \right)^{2/3} \phi_4^{4/3} \exp \left\{ - \left[a_4 \left(\frac{3\mathcal{V}}{4\alpha\gamma_4} \right)^{2/3} \phi_4^{4/3} \right] \right\}$$



Displace field from minimum. Rolls back in inflationary way. Slow roll conditions satisfied $\epsilon, \eta \ll 1$; $N_e \sim 60$. But

$$\mathcal{P}_\zeta^{inf} \ll \mathcal{P}_\zeta^{COBE}$$

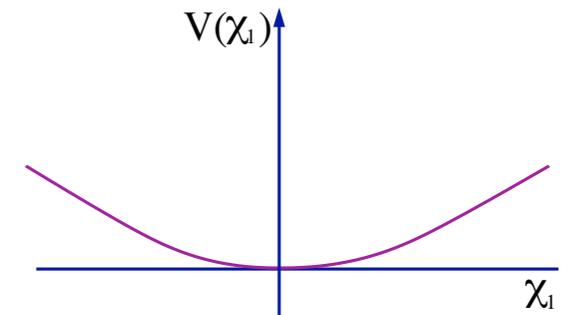
Curvaton mechanism 1

[Linde-Mukhanov; Enqvist-Sloth; Lyth-Wands; Moroi-Takahashi]

Fiber curvaton potential:

$$m_{\chi_1}^2 \sim \frac{g_s C_t W_0^2}{4\pi} \frac{M_p^2}{\mathcal{V}^{10/3}}$$

$$V \simeq V_{cur,0} + \frac{m_{\chi_1}^2}{2} \chi_1^2$$



χ_1 is very light during inflation \Rightarrow gets large quantum fluctuations:

$$\delta\chi_1 \sim H_*/2\pi$$

A power spectrum of curvaton isocurvature fluctuations is generated

$$\mathcal{P}_{\delta\chi_1/\chi_1}^{1/2} = \frac{H_*}{2\pi\chi_*} \simeq \frac{2g_s^{3/2}C_t}{\pi\beta\xi\mathcal{V}^{1/3}}$$

Curvaton isocurvature fluctuations get converted to adiabatic fluctuations, as the curvaton decays.

Need to compute the couplings of moduli to visible and hidden sector dof.

Curvaton mechanism 2

Nice feature: In LV stabilisation framework, these **couplings can be explicitly computed!**

The strongest moduli couplings turn out to be to gauge bosons.

Focusing on decay rates to visible gauge bosons [Cicoli-Mazumdar '10]

	$\hat{\chi}_1$	$\hat{\chi}_2$	$\hat{\phi}_i, \forall i = 3, 4$
$F_{\mu\nu}^{(1)} F^{(1)\mu\nu}$	$\frac{2}{\sqrt{3} M_p}$	$\sqrt{\frac{2}{3}} \frac{1}{M_p}$	$\frac{3 (\ln \mathcal{V})^{\frac{3}{4}}}{2 a_i \mathcal{V}^{1/2} M_p}$

$$\Gamma_{\phi_j \rightarrow gg} = \frac{27 (\ln \mathcal{V})^{\frac{3}{2}} m_{\phi_j}^3}{64\pi \mathcal{V} M_p^2} \simeq \frac{M_p}{\mathcal{V}^4}, \quad j = 3, 4$$

Using decay rate of generic modulus φ to gauge bosons g .

$$\Gamma_{\chi_1 \rightarrow gg} = \frac{1}{4\pi} \frac{m_{\chi_1}^3}{M_p^2} \simeq \frac{M_p}{\mathcal{V}^5}, \quad \Gamma_{\chi_2 \rightarrow gg} = \frac{1}{8\pi} \frac{m_{\chi_2}^3}{M_p^2} \simeq \frac{M_p}{\mathcal{V}^{9/2}},$$

$$\Gamma_{\varphi \rightarrow gg} = \frac{N_g \lambda^2 m_\varphi^3}{64\pi}$$

The inflaton ϕ_4 decays before the curvaton χ_1

Non-Gaussianities from curvaton

When curvaton decays, its isocurvature fluctuations get converted into adiabatic ones whose amplitude is ($\Omega \ll 1$)

[Lyth-Ungarelli-Wands '01]

$$\mathcal{P}_\zeta^{1/2} = \frac{2}{3} \Omega \mathcal{P}_{\delta\chi_1/\chi_1}^{1/2} \simeq \frac{\sqrt{2}}{576\pi} \frac{(\beta\xi)^2 W_0}{g_s^{5/2} C_t^{3/2} \mathcal{V}}$$

$$\Omega = \rho_{cur}/\rho_\gamma \simeq \left[\frac{1}{6} \left(\frac{\chi_\star}{M_p} \right)^2 \left(\frac{m_\chi}{\Gamma_{\chi_1}} \right)^{1/2} \right] \simeq \left[\frac{\sqrt{2}}{768} \frac{(\beta\xi)^3 W_0}{g_s^4 C_t^{5/2} \mathcal{V}^{2/3}} \right]$$

Imposing that this amplitude matches COBE $\mathcal{P}_\zeta^{1/2} = 4.8 \times 10^{-5}$



constraint on

$$C_t^{3/2} \simeq 16 \frac{(\beta\xi)^2 W_0}{g_s^{5/2} \mathcal{V}}$$

Non-Gaussianities of local-form appear naturally from

$$\zeta = \frac{\Omega}{3} \frac{\delta\rho_{\chi_1}}{\rho_{\chi_1}}$$

$$\zeta = \zeta_G + \frac{3}{5} f_{NL} \zeta_G^2$$



$$f_{NL} = \frac{5}{4\Omega} \simeq \frac{679 C_t^{5/2} g_s^4 \mathcal{V}^{2/3}}{W_0 \beta^3 \xi^3} = 10^5 \frac{(\beta\xi W_0^2)^{1/3}}{g_s^{1/6} \mathcal{V}}$$

Note that Ω tells how efficient the conversion is:

small $\Omega \Leftrightarrow$ low efficiency \Leftrightarrow large isocurvature fluct. \Leftrightarrow large non-gauss.

large $\Omega \Leftrightarrow$ high efficiency \Leftrightarrow small isocurvature fluct. \Leftrightarrow small non-gauss.

Explicit examples

1) Small volume, large f_{NL}

\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



$$f_{NL} \sim 57$$

Observable by Planck!

2) Larger volume, smaller f_{NL}

\mathcal{V}	a_4	ξ	g_s	W_0	α	A_4	γ_4
10^6	$\frac{1}{8}$	1	$\frac{1}{100}$	10	10	$\frac{1}{10}$	10



$$f_{NL} \sim 2$$

In both cases, scale of inflation is $\sim 10^{15}$ GeV

Conclusions

Generic string compactifications have several moduli. These can be relevant for inflation and post-inflation evolution =>

Non-standard ways to generate primordial fluctuations, as e.g. curvaton mechanism.

The LV scenario constitutes a perfect theoretically controlled string framework to study these possibilities.

Large Volume suppressed masses for different (closed string) moduli allows for such a picture. Some fields remain light, some stay heavy, during inflation

Couplings to hidden and visible sectors can be explicitly computed
=> explicit realisation of the curvaton scenario in string theory!

Large non-gaussianity can be generated, which may be observable soon by PLANCK!