Non-Gaussianity in Large Volume Inflation

SUSY 2010
Bonn

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with

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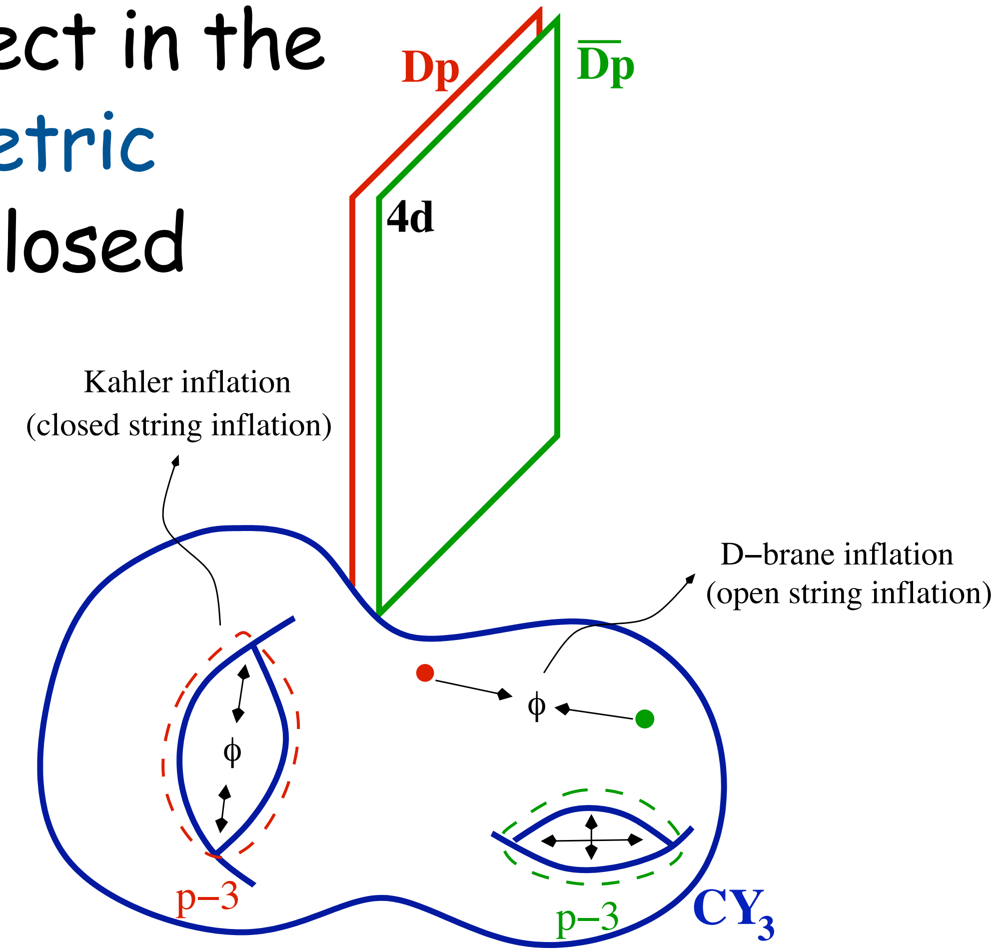
Motivation

String inflation has become a very active subject in the last years. Here, inflaton finds a natural geometric 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)

Most slow roll inflationary scenarios in string theory consider a single field dynamics for simplicity. Generic inflationary predictions are:

- negligible tensor modes (scalar to tensor ratio $r \ll 1$)

- nearly Gaussian spectrum ($f_{NL} \sim 0$)

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

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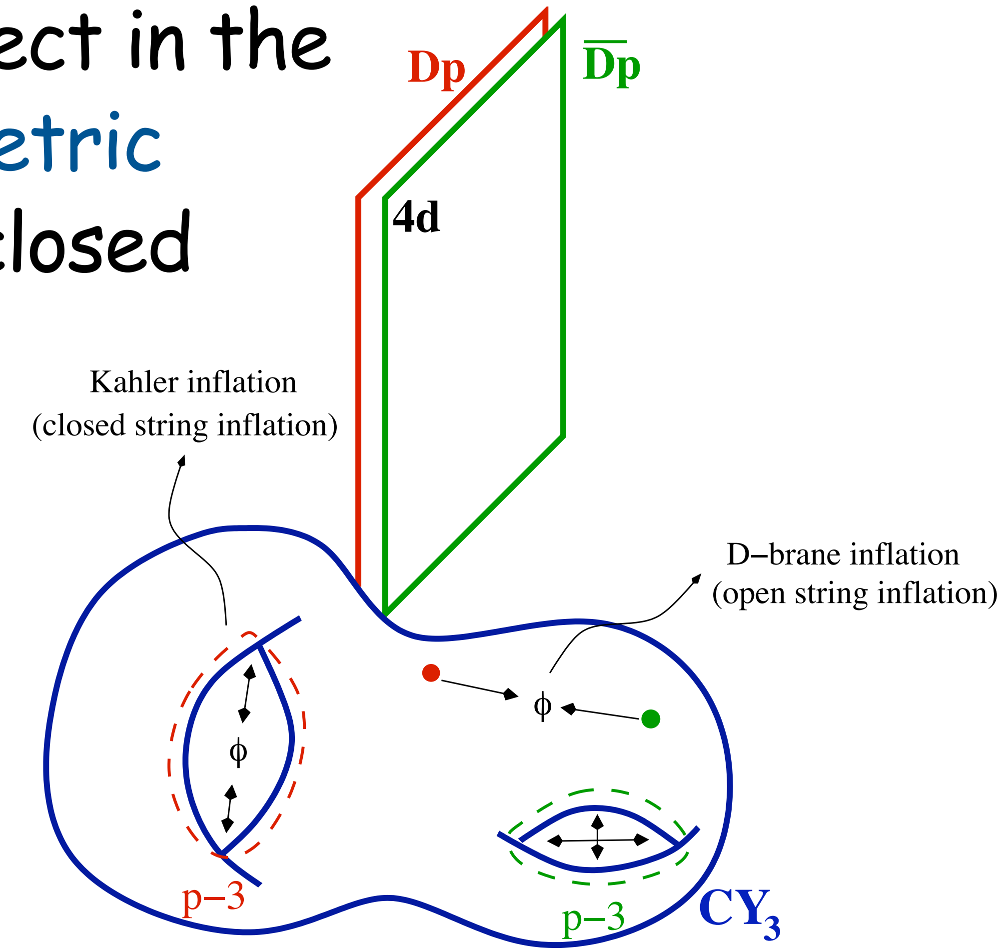

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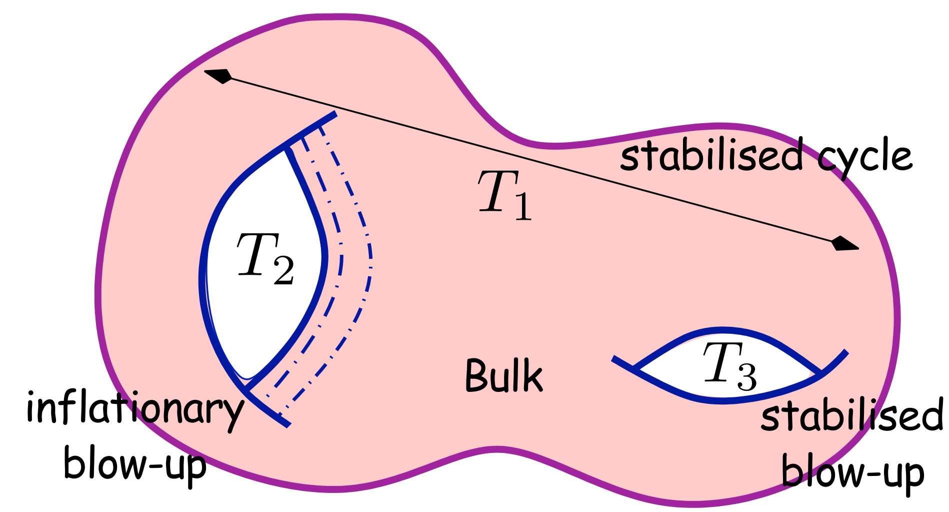
Kähler moduli cosmology

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]
- Fiber Inflation [Cicoli-Burgess-Quevedo, '08]



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

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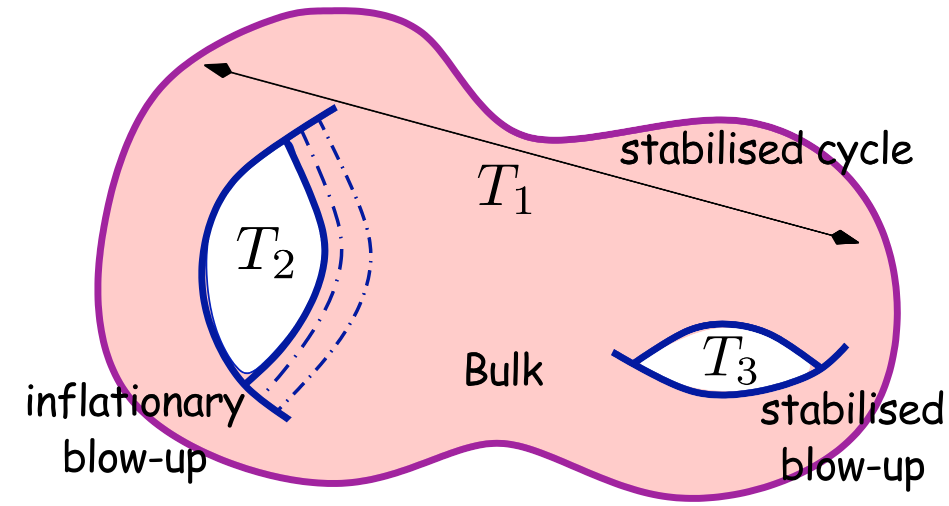

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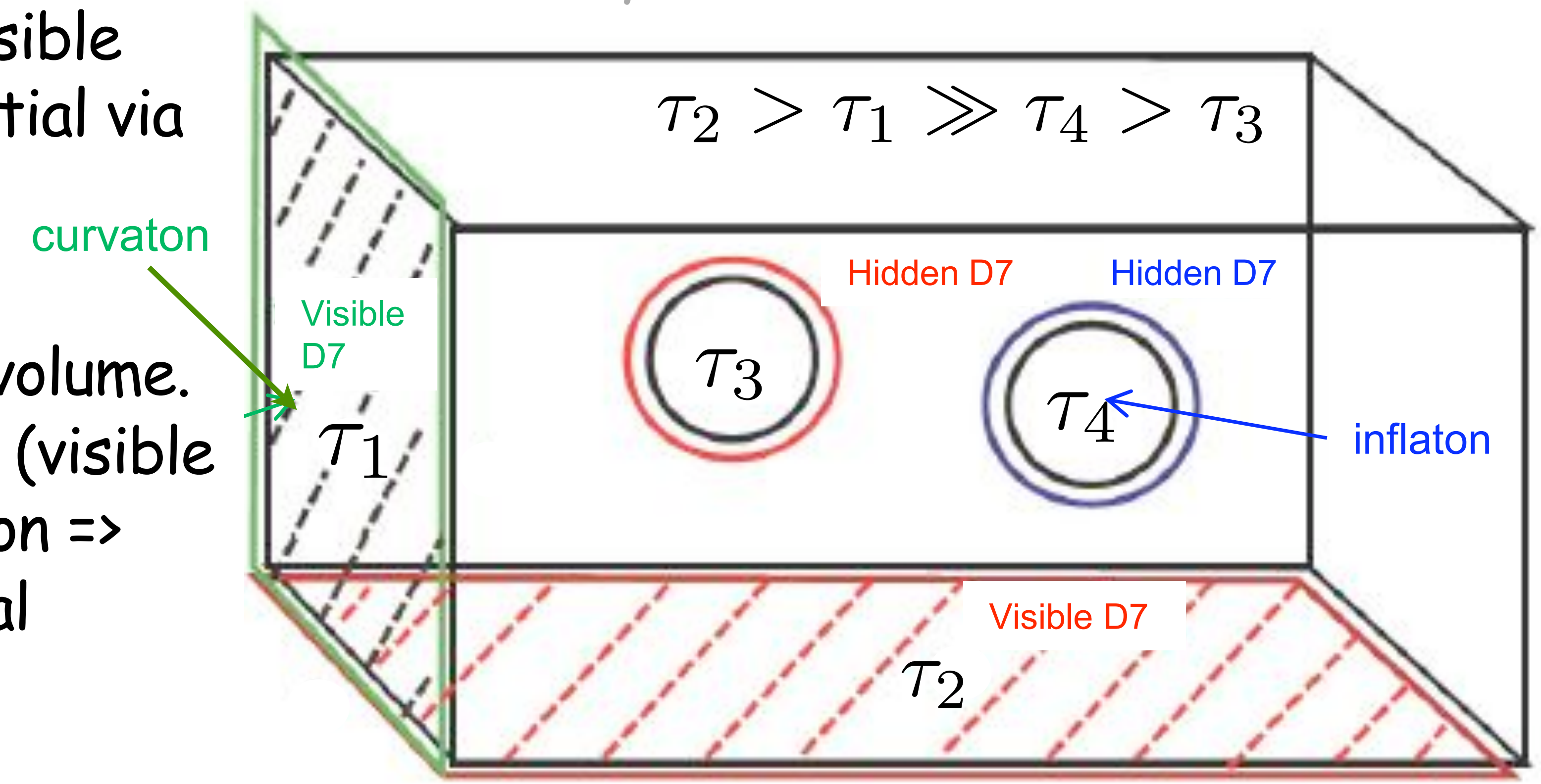
Is it possible to obtain large non-Gausssianities??

The set up

Compactification with minimal field content: CY3 with K3 fibration controlled by large cycles (τ_1, τ_2) together with 2 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 sector lives here), which provide potential via loop corrections.

Geometry cartoon [from Cicoli '10]



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 => 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 => 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

Volume can be written as:

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

Kähler potential (with α' corrections):

$$K = -2\, \ln \left[\mathcal{V} + \frac{\xi}{2\, g_s^{3/2}} \right] ; \qquad \xi = \frac{(h_{1,2} - h_{1,1})\zeta(3)}{(2\pi)^3} > 0$$

The superpotential is: $W \simeq W_0 + A_3\, e^{-a_3\, T_3} + A_4\, e^{-a_4\, T_4}$

$$a_i = 2\pi/N_i$$

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 before loop corrections:

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

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

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

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

Including subleading string loop corrections to K give correction to scalar potential of form:

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

$$B > 0$$

This fixes second combination of (τ_1, τ_2) at

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

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Cosmological evolution

During inflationary evolution, (ϕ_3, χ_2) are heavy => $(\mathcal{V}, \tau_3)$ 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:

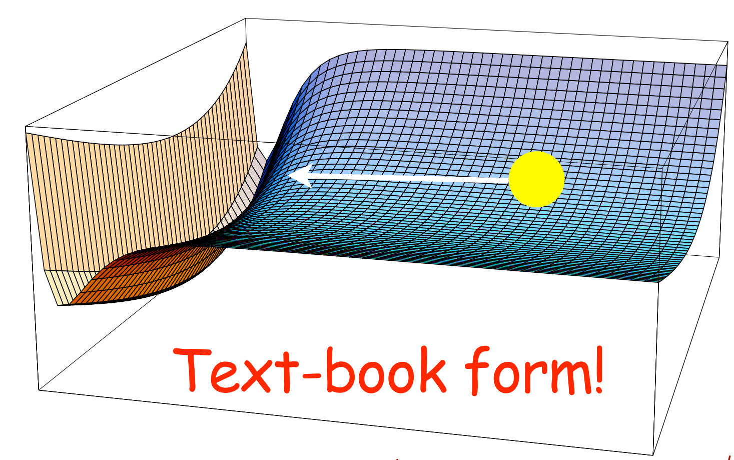
$$H^2 \sim \frac{M_p^2}{\mathcal{V}^3}$$

$$m^2_{\phi_3} \sim \frac{M_p^2}{\mathcal{V}^2}\,, \qquad m^2_{\chi_2} \sim \frac{M_p^2}{\mathcal{V}^3} \qquad \Longrightarrow \qquad \text{heavy!}$$

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

Inflaton potential: [Conlon-Quevedo '05]

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



$$V = V_0\left(1 - A\, e^{-a\,\phi}\right)$$

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

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

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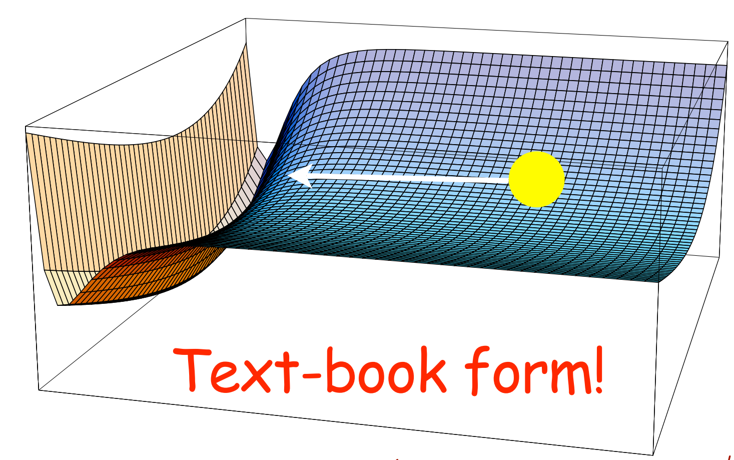

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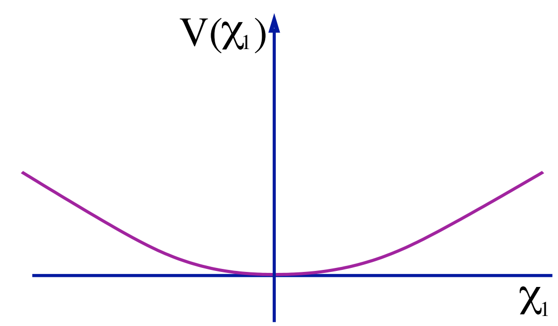
Curvaton mechanism 1

Fiber curvaton potential:

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



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

χ_1 gets large quantum fluctuations: $\delta\chi_1 \sim H_\star/2\pi$

A power spectrum of curvaton isocurvature fluctuations is generated

[Lyth-Ungarelli-Wands '02]

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

Curvaton isocurvature fluctuations get converted to adiabatic as 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.

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

Decay rate of generic modulus φ to gauge bosons g.

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

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

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

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

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 depends on

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

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

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

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

Considering nongaussianities of local-form $\zeta = \zeta_G + \frac{3}{5}\,f_{NL}\,\zeta_G^2$

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

Note that Ω tells how efficient the conversion is:

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

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

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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

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

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

$\Rightarrow$ $f_{NL} \sim 2$

In both cases, scale of inflation is ~ 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 stringy-controlled 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!