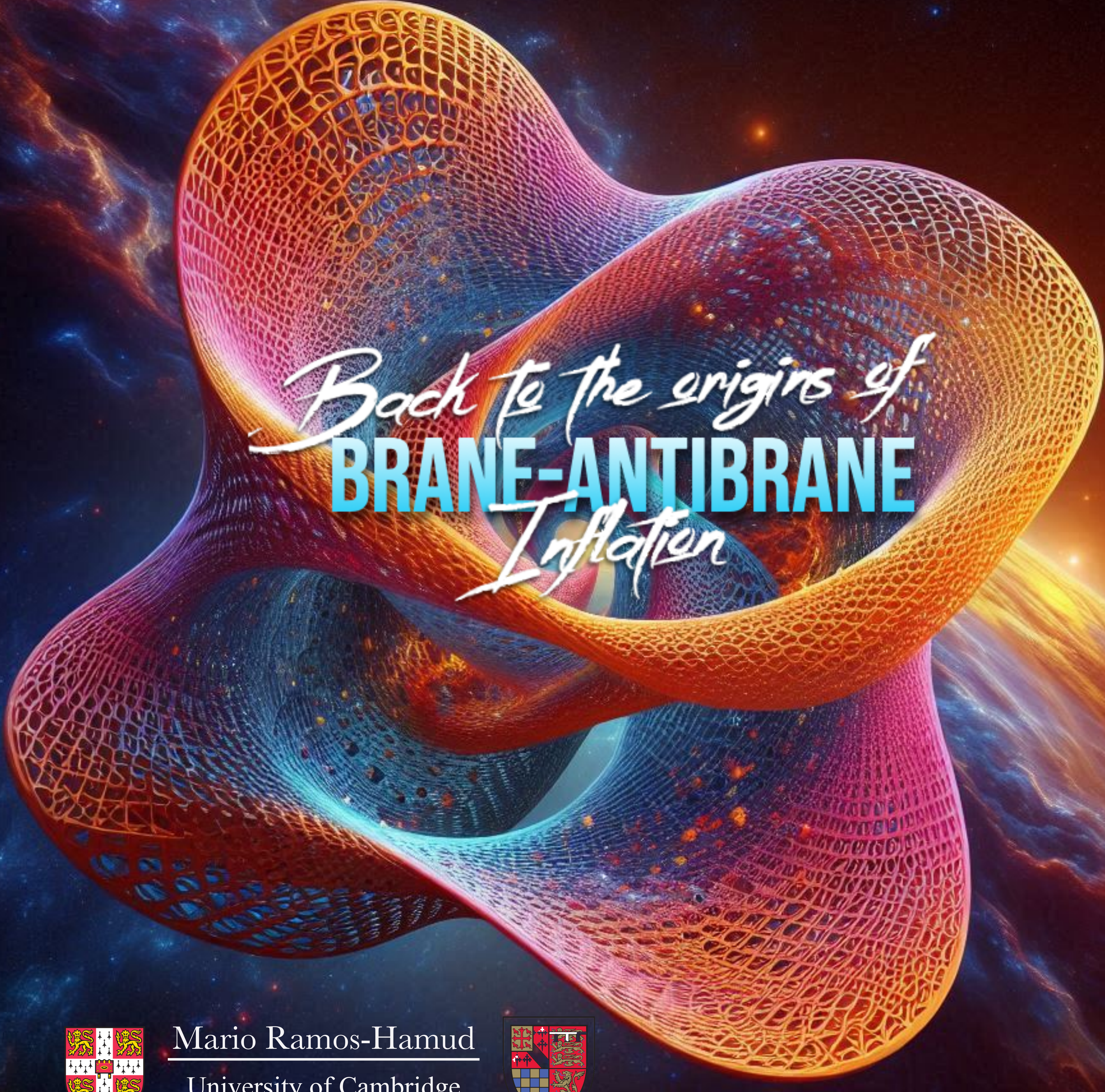
WISPs in String Cosmology 2024

Department of Physics and Astronomy "Augusto Righi Bologna, Italy

Back to the origins of BRANE-ANTIBRANE Inflation



Mario Ramos-Hamud

University of Cambridge

Thursday, 23th October 2024

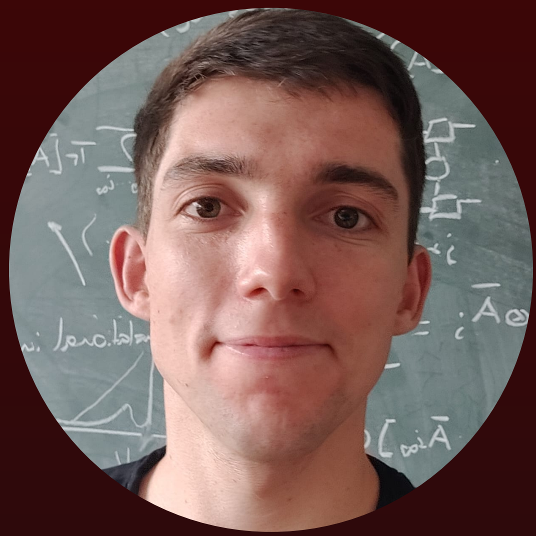
Based on arXiv: 2410.00097

CONACYT

CAMBRIDGE COMMONWEALTH EUROPEAN AND INTERNATIONAL TRUST

Collaboration

M. Cicoli

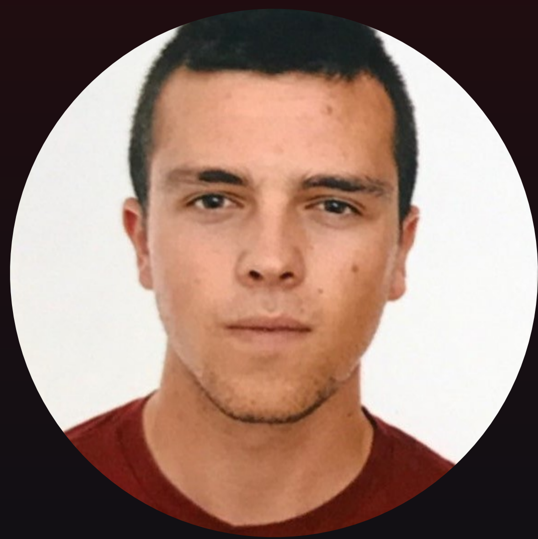


C. Hughes

A. Rakin

F. Marino

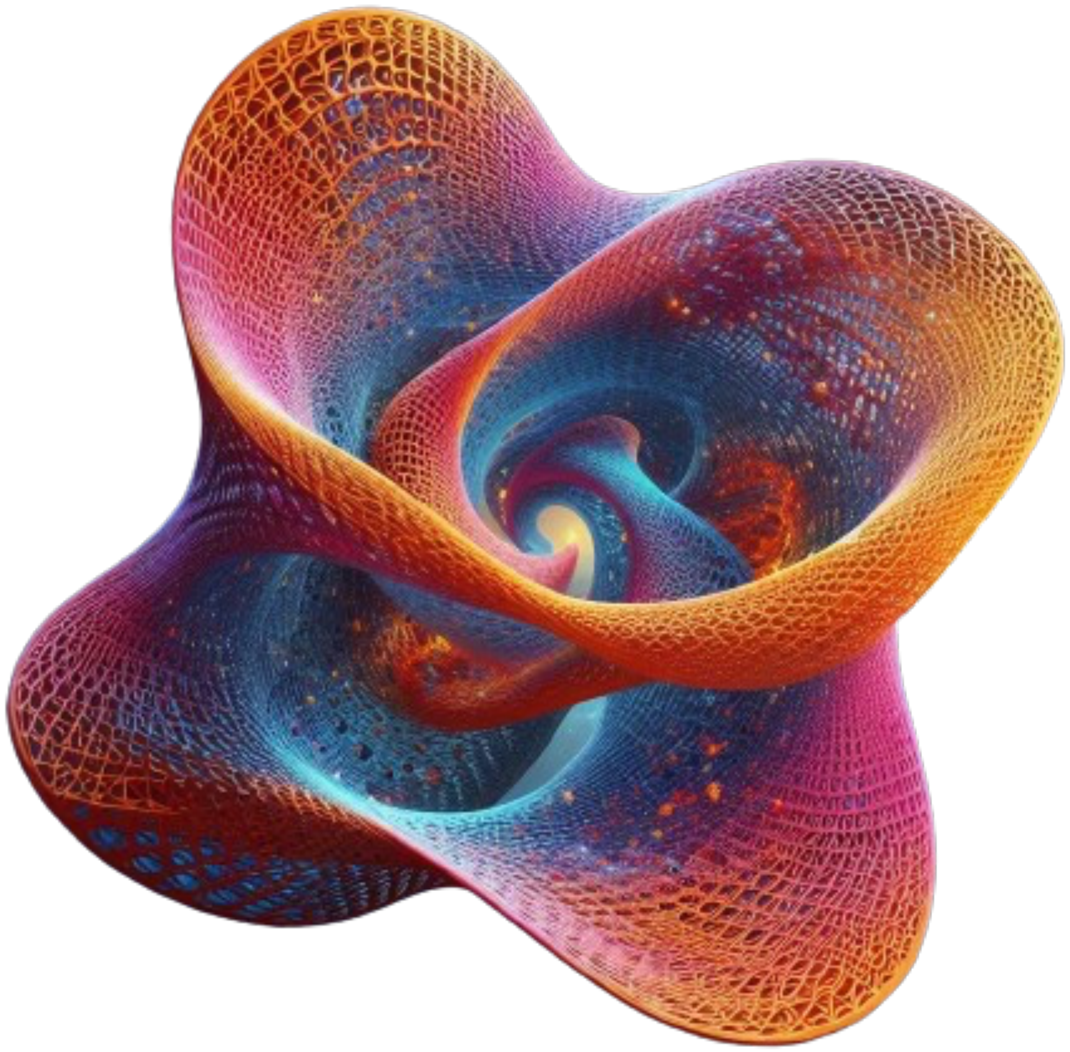
F. Quevedo



G. Villa

Outline

- Motivation
- Late-time modulus stabilisation
- Inflation from string theory
- Summary
- Future work



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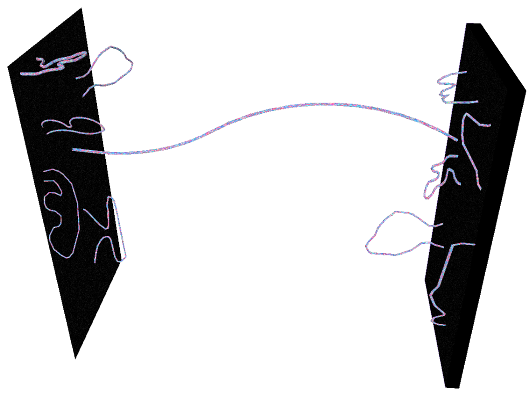

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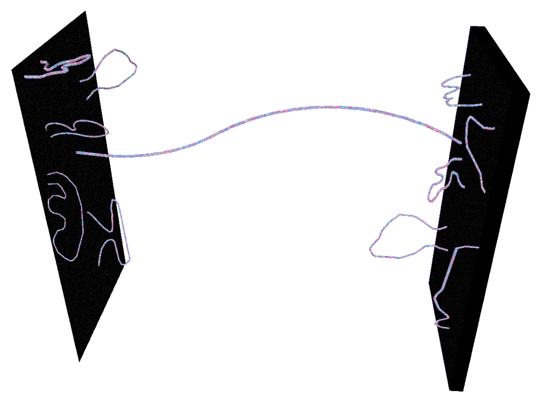

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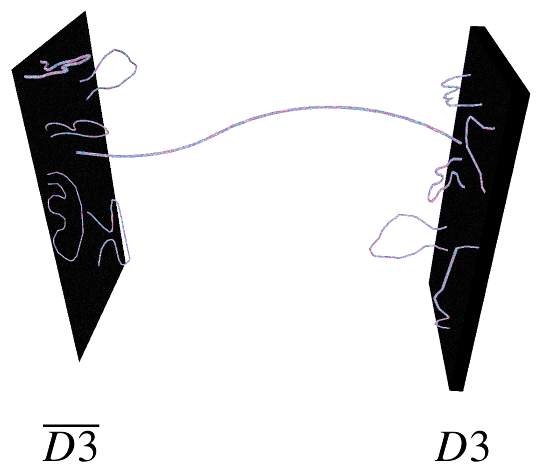

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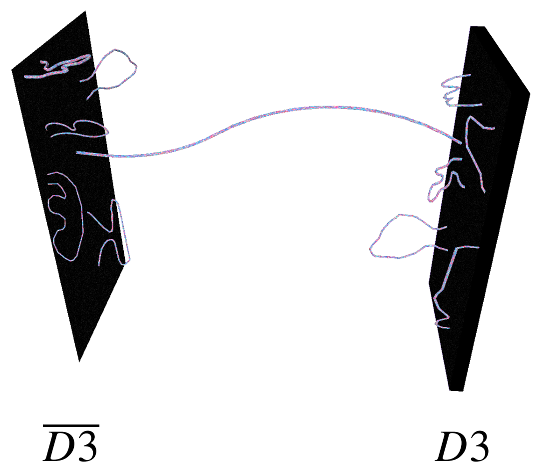

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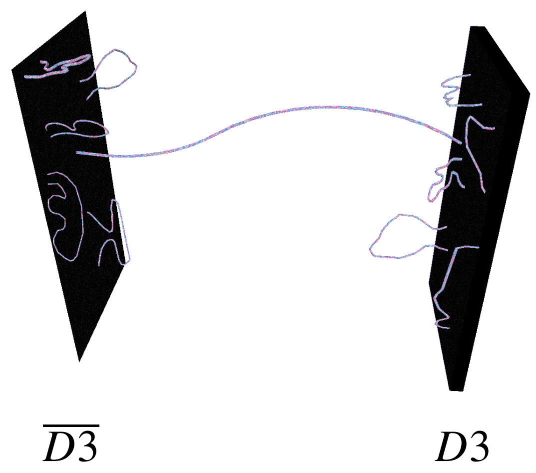

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We provide concrete examples within string theory with **modulus stabilisation** and inverse power law **inflation** potential in the presence of the volume modulus.

Late time modulus stabilisation

Perturbative corrections

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IIB STRING COMPACTIFICATIONS

Perturbative corrections

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†: *The uplifting could come from several different sources like, for example, a D3-brane in a different throat from the inflationary one or dilaton-dependent non-perturbative effects at singularities.*

Perturbative modulus stabilisation

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Given that most of the known Calabi-Yau threefolds with $\xi > 0$ have $\xi \in (0.1, 1.5)$, we fix $c = \zeta(3)/\pi^3$ obtaining

$$\theta \simeq 1 \qquad \Leftrightarrow \qquad \alpha \simeq 4.78\sqrt{g_s}\, e^{-\frac{0.02}{g_s^2}} \simeq 0.22 \qquad \text{for} \qquad g_s \simeq 0.1\,,$$

exactly in the right ballpark if α were given in terms of the 1-loop β-function coefficient of an $SU(2)$ theory as $\alpha = \beta_0/(8\pi) = 3/(4\pi) \simeq 0.24$.

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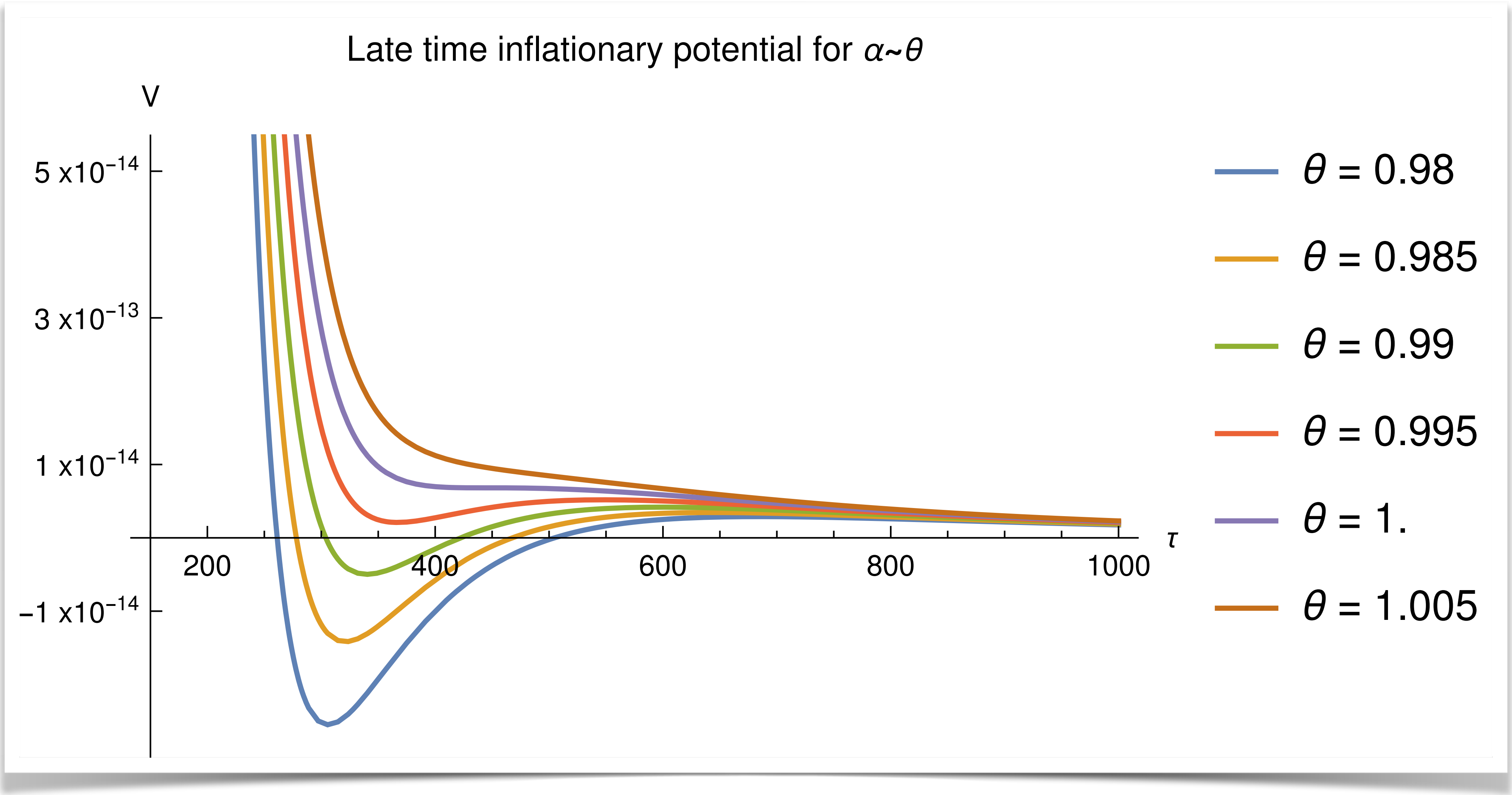

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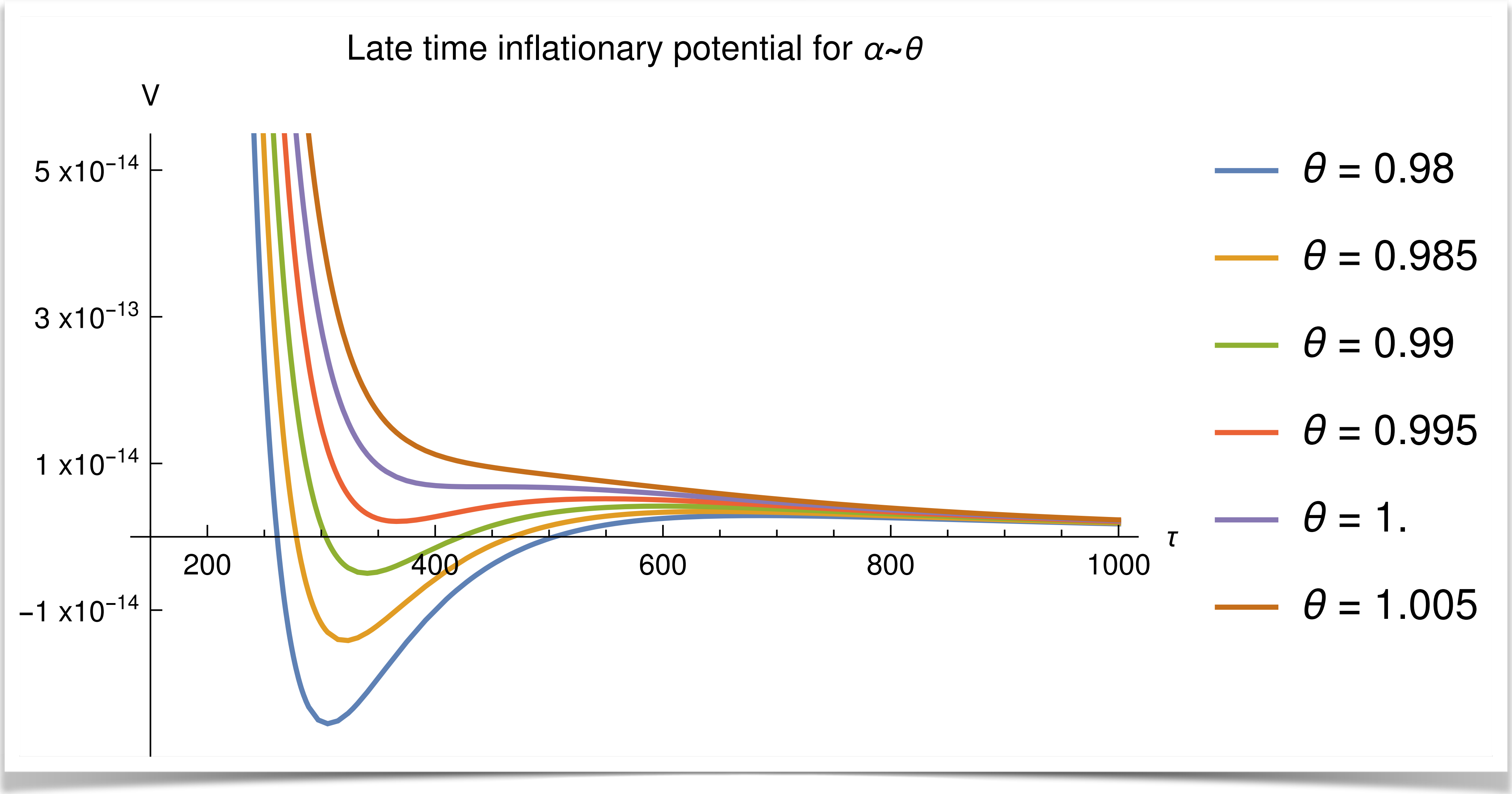

Figure: We set $\xi = g_s = 0.1$ and $T_7 = 2\pi$. By increasing θ we move from AdS to dS and finally to a runaway. In particular, the red curve shows a dS minimum at $\tau_{\rm min} \sim 370$ and $V_{\rm min} \ll 10^{-14}$ for an appropriate choice of θ.

Inflation from string theory

Brane-antibrane inflation

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Type IIB string theory compactified on a CY threefold in the presence of fluxes:

$$ds^2 = \tilde{g}_{MN} dx^M dx^N = \left(1 + \frac{e^{4\rho(y)}}{\mathcal{V}^{2/3}}\right)^{-1/2} ds_4^2 + \left(1 + \frac{e^{4\rho(y)}}{\mathcal{V}^{2/3}}\right)^{1/2} ds_{\mathrm{CY}}^2.$$

The corresponding inter-brane potential is given by

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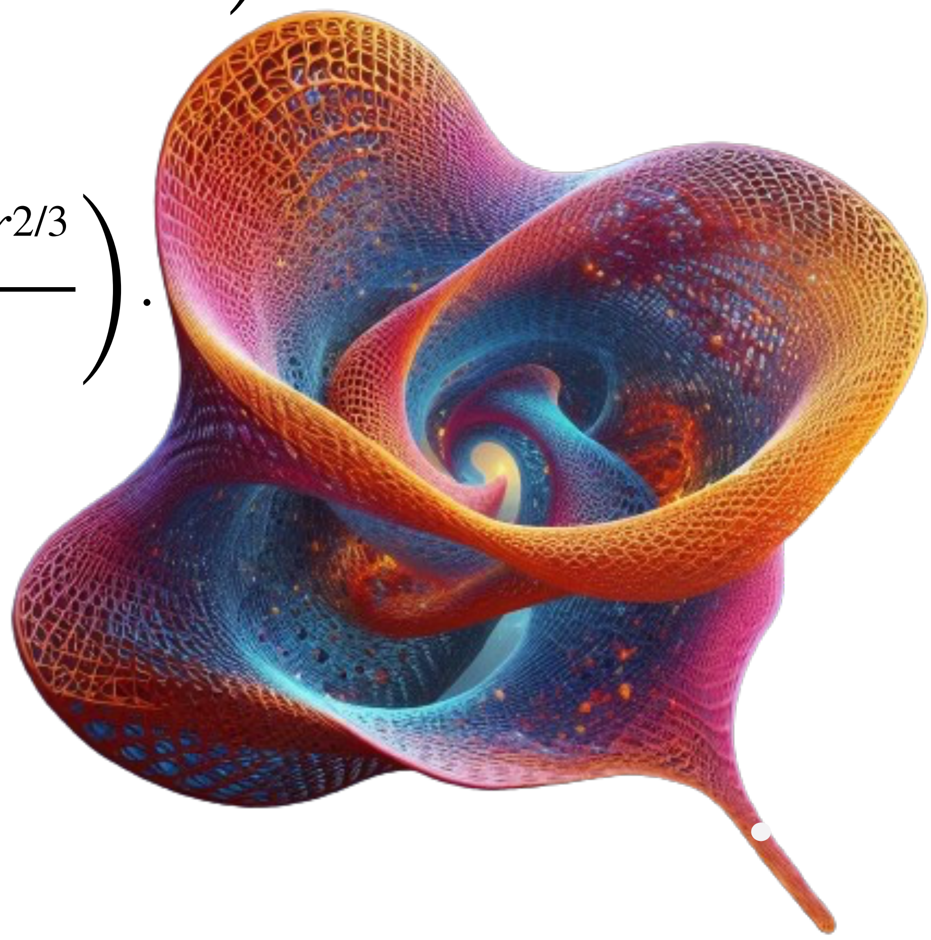

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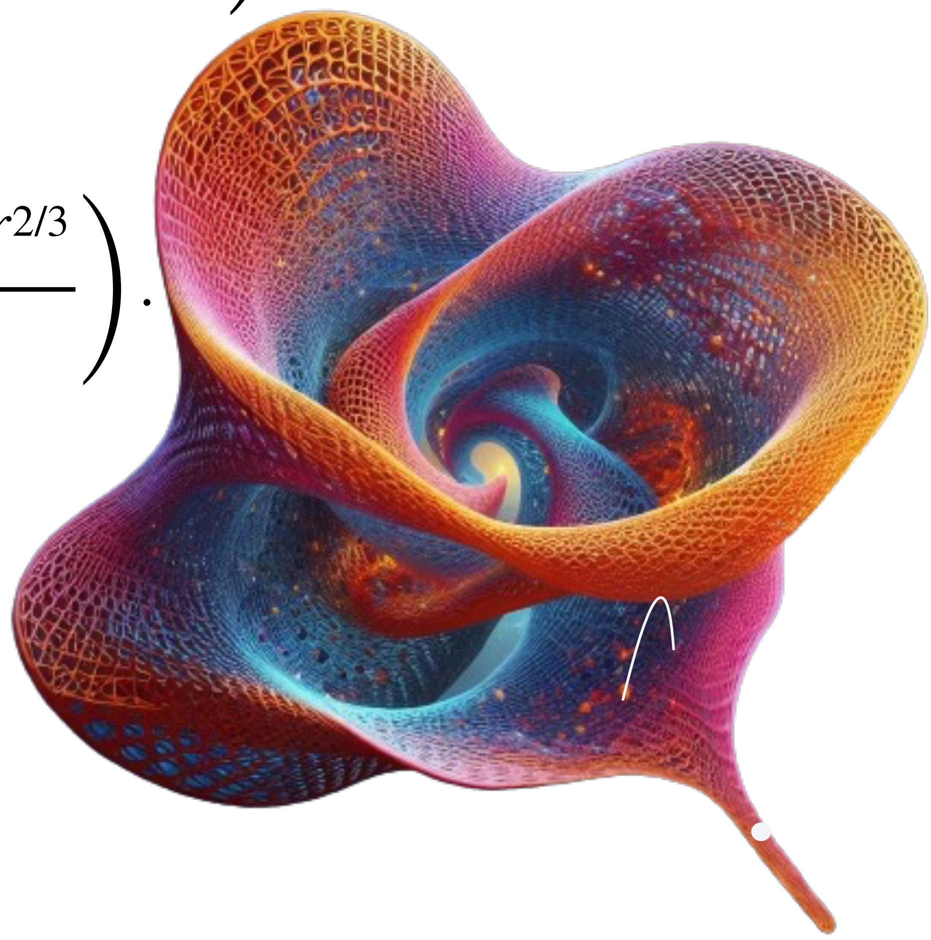

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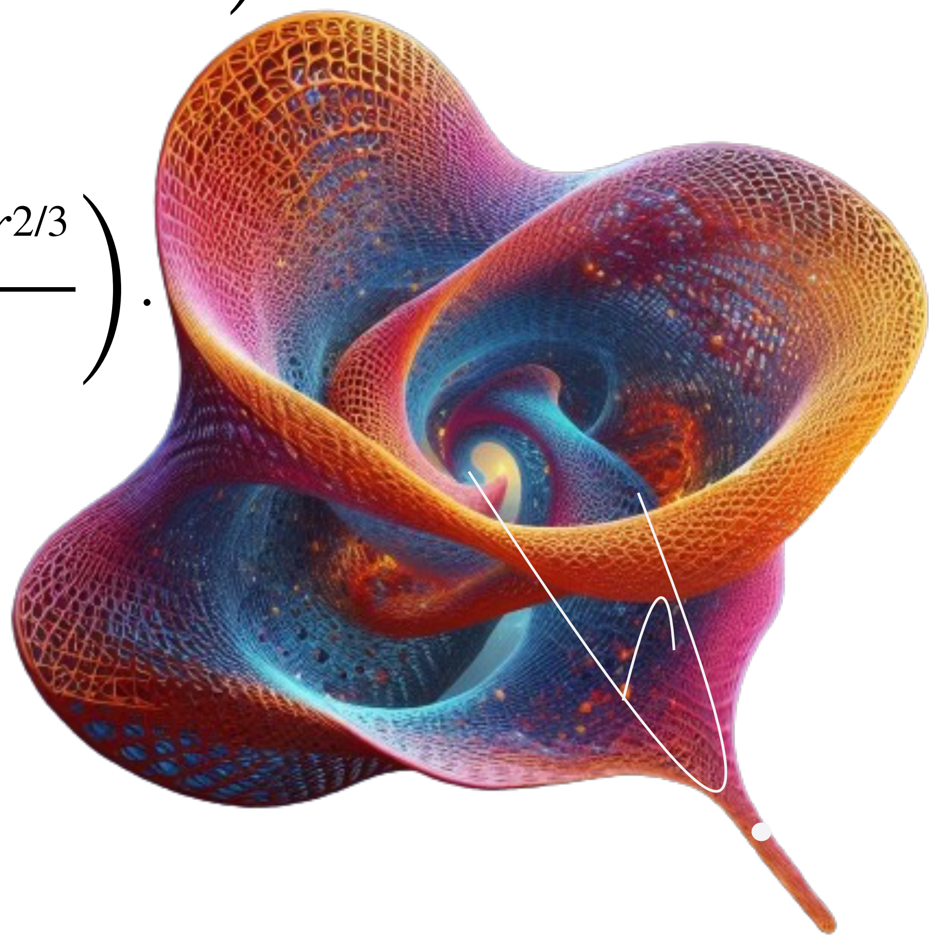

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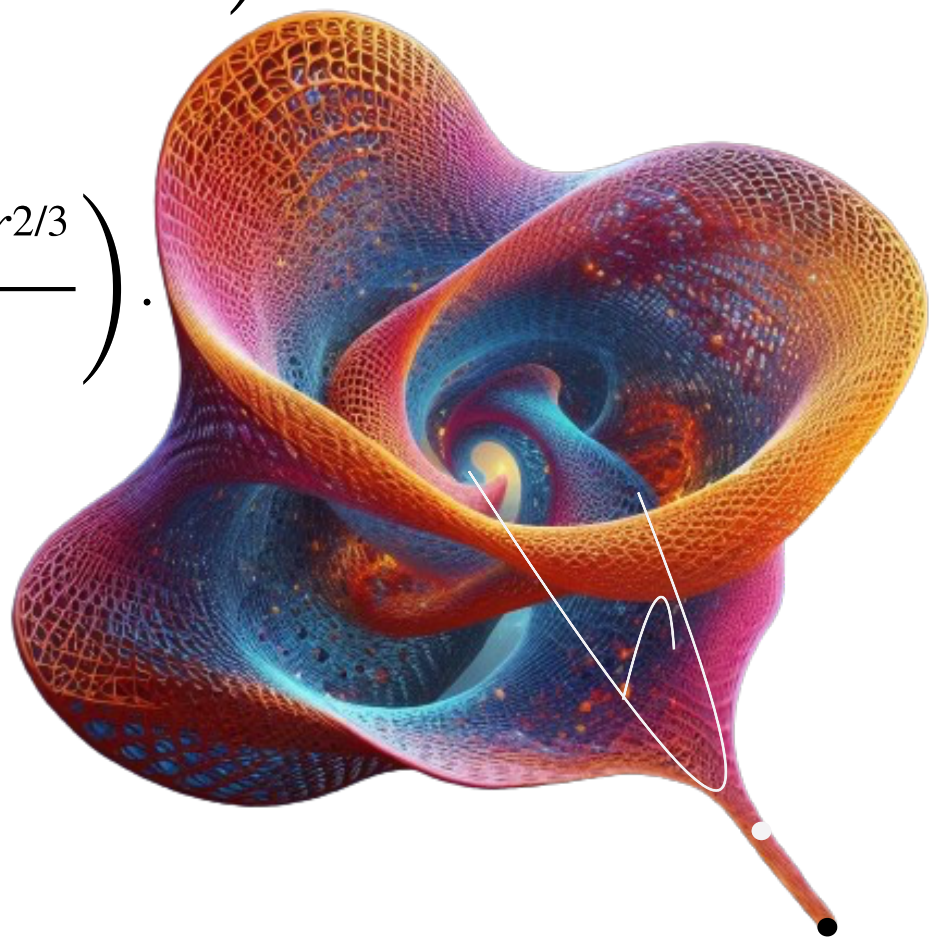

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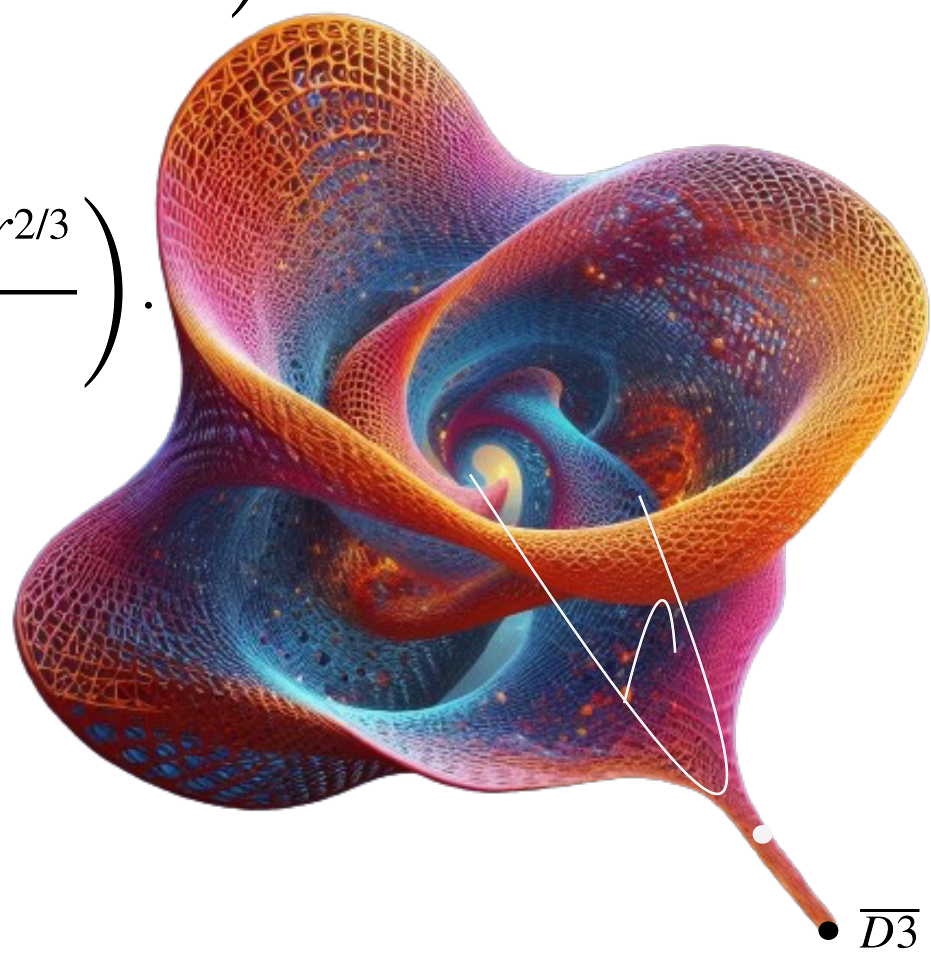

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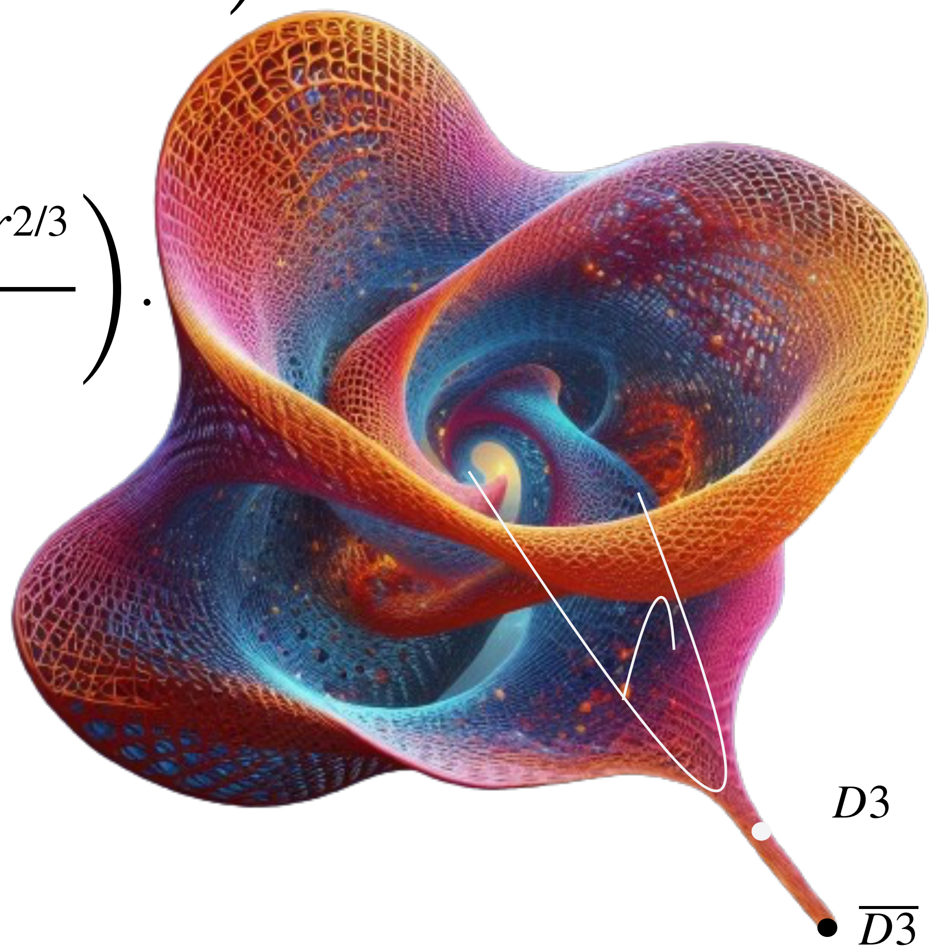

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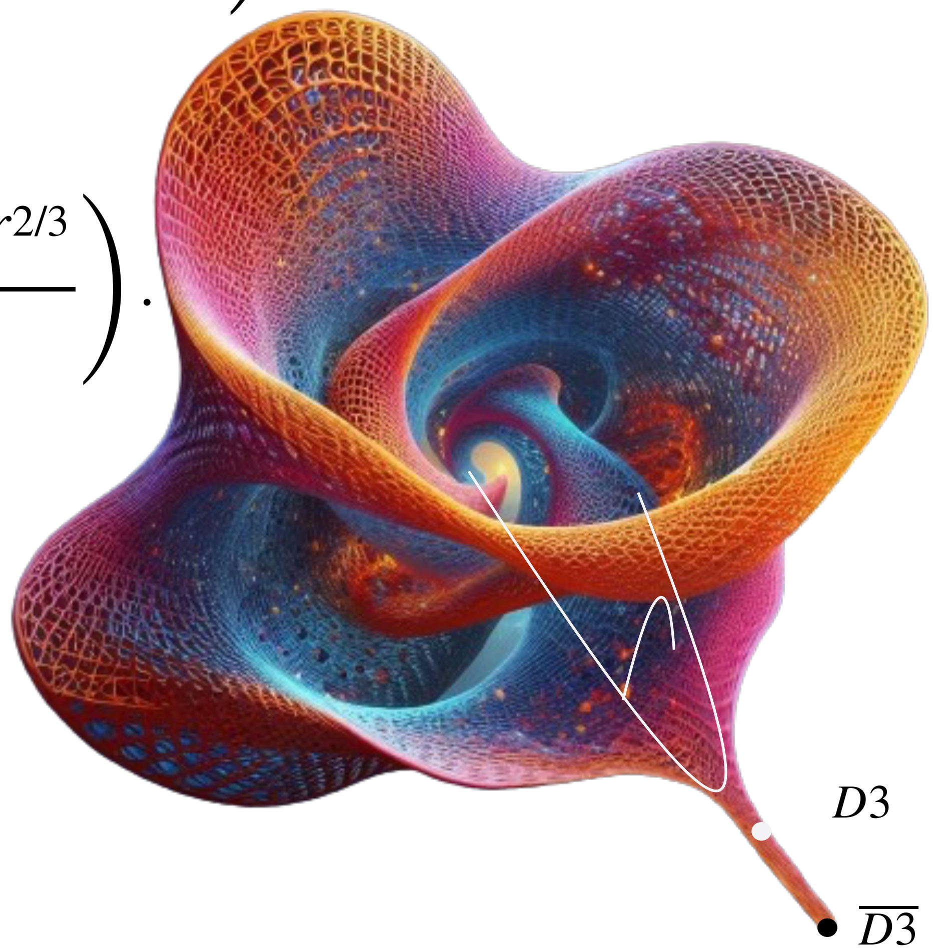

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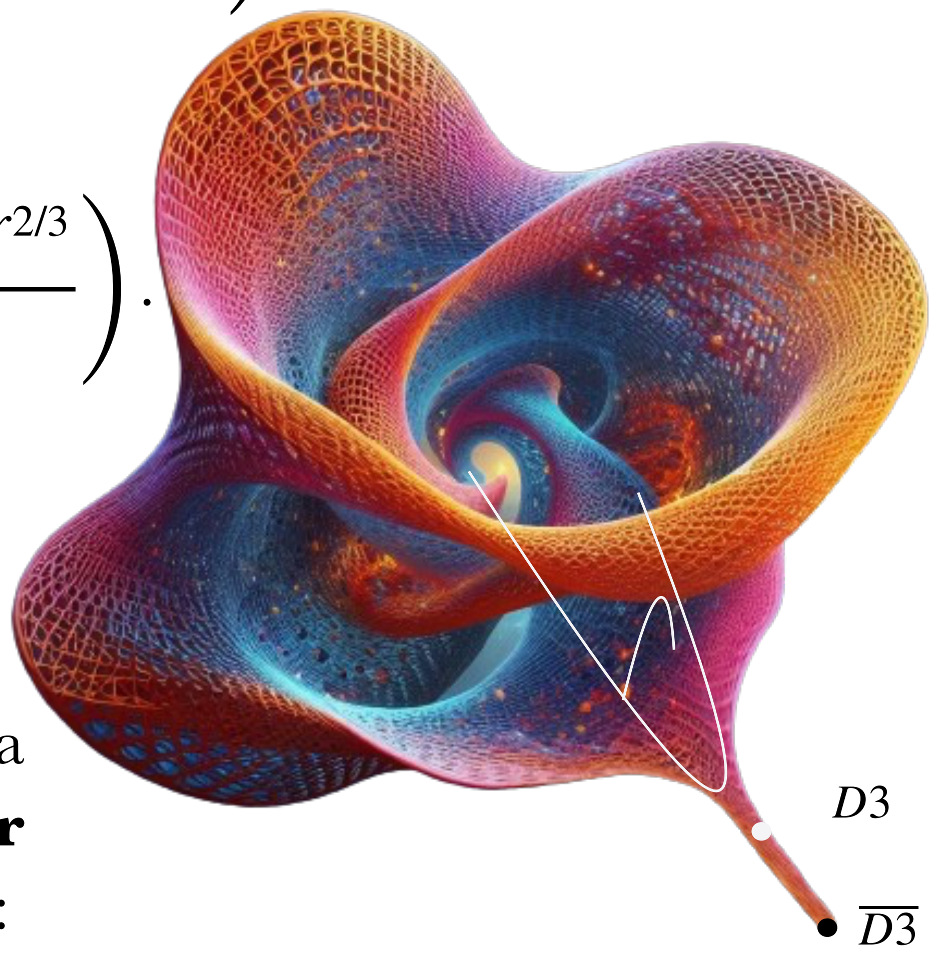

Nilpotent superfield framework:

The setup can be studied using non-linear SUSY with a **goldstino** superfield X breaking SUSY, a **Kähler modulus** $\tau \equiv (T + \overline{T})$ and the **inflaton** r defining the EFT:

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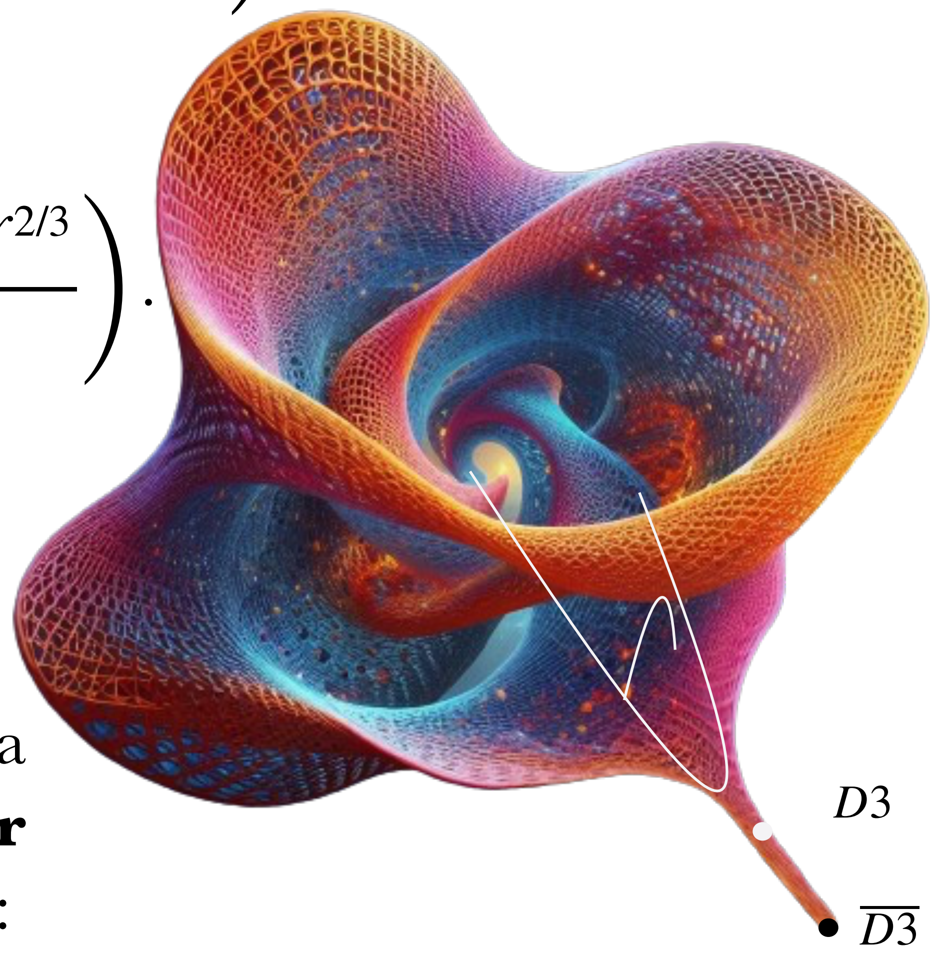

Nilpotent superfield framework:

The setup can be studied using non-linear SUSY with a **goldstino** superfield X breaking SUSY, a **Kähler modulus** $\tau \equiv (T + \overline{T})$ and the **inflaton** r defining the EFT:

$$K = -3 \ln\left[f(\sigma) + (X + \overline{X})\, g(\sigma) - X\overline{X} h(\sigma)\right] \quad \text{and} \quad W = W_0 + X\, W_X(r)\,,$$

where $\sigma = \tau - \frac{1}{6}\left(M_{KK} r\right)^2$, and not τ, is the modulus stabilised during inflation guaranteeing the **absence of the η-problem**. The corresponding scalar potential is then

$$V = \frac{1}{U}\left[\left(f' W_X - 3g' W_0\right)^2 - f''\left(f W_X^2 - 6g W_X W_0 - 9h W_0^2\right)\right]$$

With $U \equiv 3f^2\left(2gf'g' - fg'^2 + f'^2 h - f''(g^2 + fh)\right)$ such that at tree-level† $V = \frac{W_X(r)^2}{3\sigma^2}$.

Then, we divide out analysis in two possible scenarios:

- Non-trivial linear term: $g(\sigma) \neq 0$.
- Vanishing linear term: $g(\sigma) = 0$.

†: *At tree level* $f = \sigma, g = 0$ *and* $h = 1$.

Brane-antibrane inflation

Type IIB string theory compactified on a CY threefold in the presence of fluxes:

$$ds^2 = \tilde{g}_{MN} dx^M dx^N = \left(1 + \frac{e^{4\rho(y)}}{\mathscr{V}^{2/3}}\right)^{-1/2} ds_4^2 + \left(1 + \frac{e^{4\rho(y)}}{\mathscr{V}^{2/3}}\right)^{1/2} ds_{\mathrm{CY}}^2.$$

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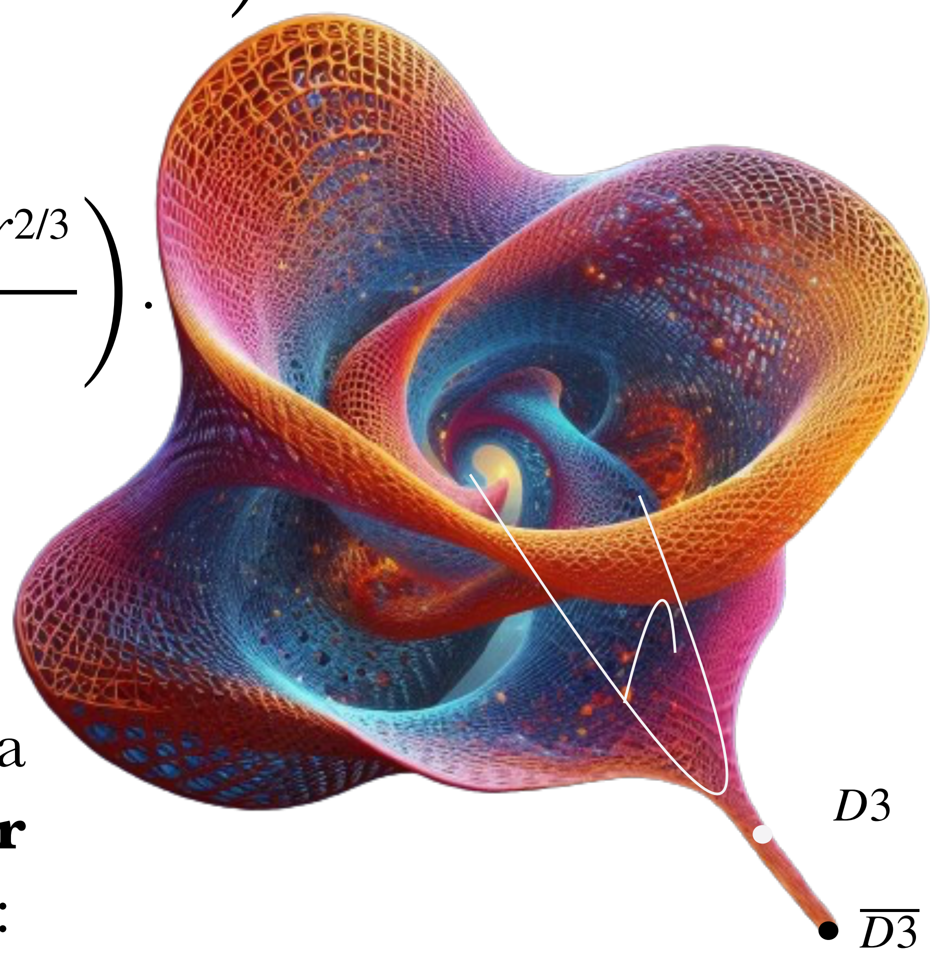

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($\overline{D3}$-brane contribution if we identify W_X with the warp factor).

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For large field values, this can be expanded as $V_{\rm inf}(\varphi) \simeq C_0\left(1 - \dfrac{C_1}{\varphi^4}\right)$ *(power-law with $n = 4$)*,

$$\text{where } C_0 \equiv \frac{9\xi}{192\sqrt{2}(3\pi)^{9/4}g_s^6}\frac{e^{-9\rho}}{W_0^{5/2}} \qquad \text{and} \qquad C_1 \equiv \frac{9\mathcal{D}_0 T_3^2}{4M_{KK}^4}\,.$$

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Uplifted dS minimum during inflation

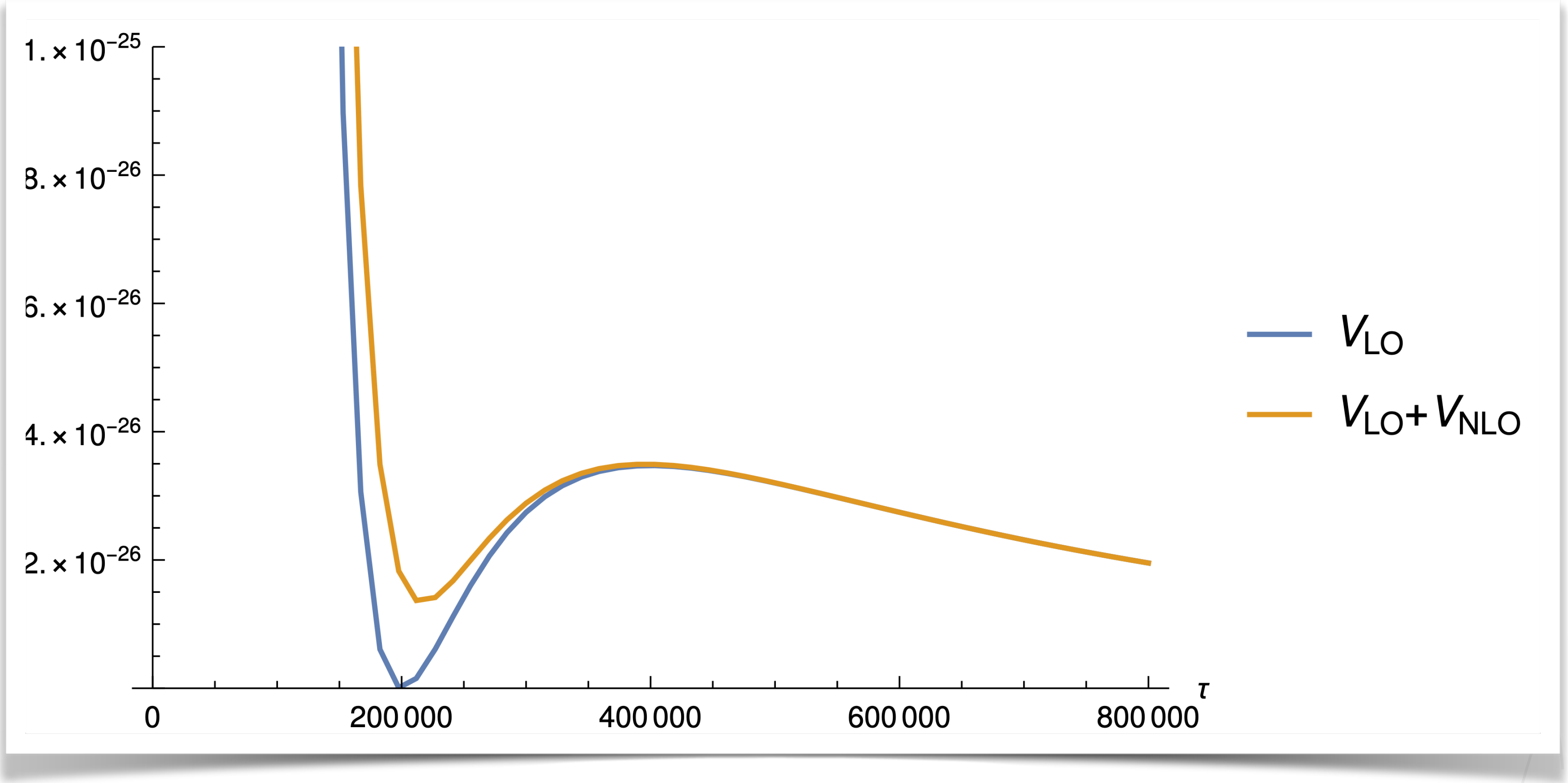

Figure: The parameter choices of this example are $\theta = 0.994$, $g_s = 1/15$, $W_0 = 1$, $W_X = 10^{-6}$, $T_7 = 2\pi$ *and* $\xi = 0.1$.

Early and late time potentials

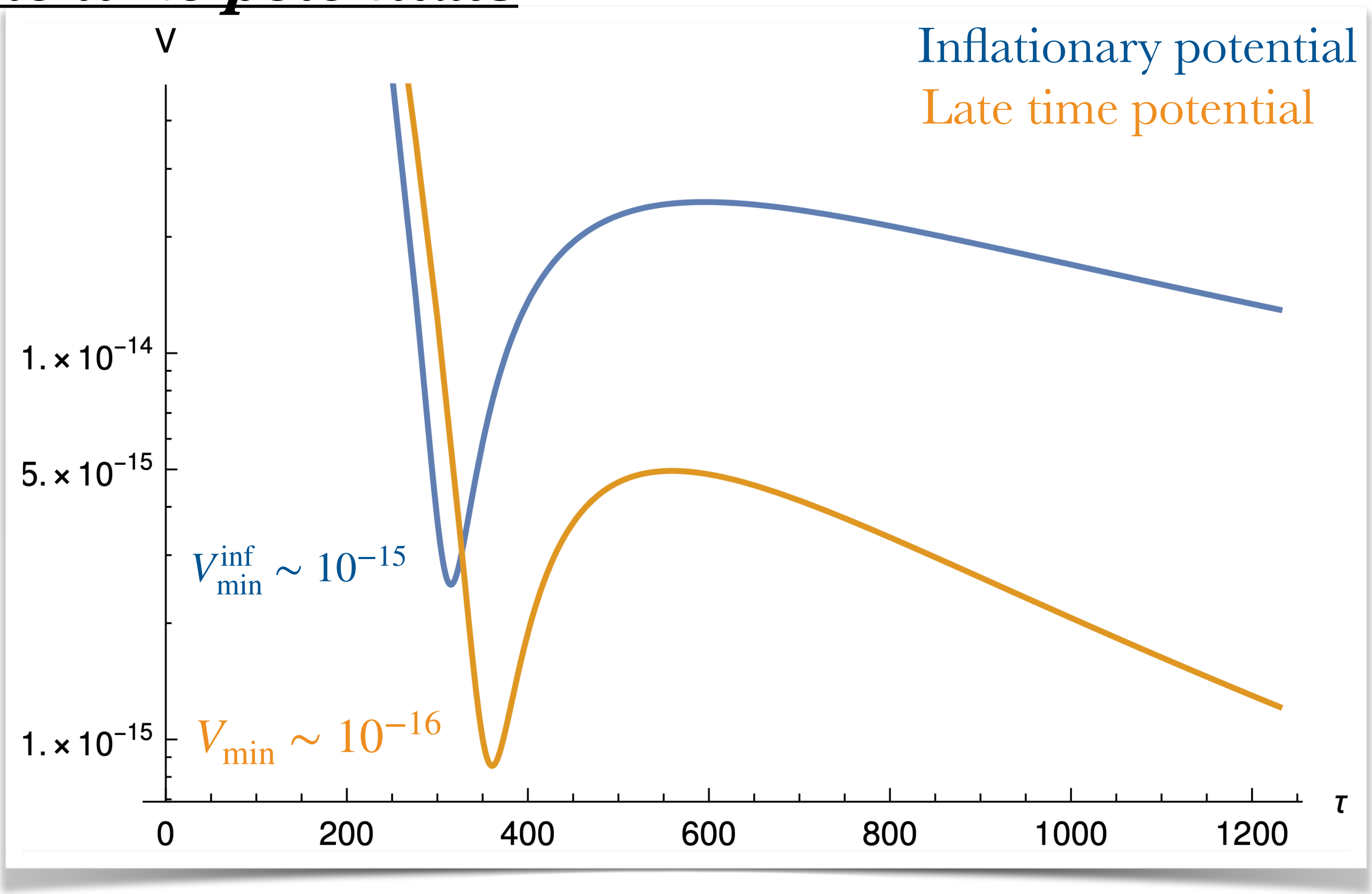

Figure: The parameters used to generate this plot are $\xi = g_s = 0.1$, $W_0 = 1$, $W_X = 10^{-3}$ *and* $T_7 = 2\pi$, *while* $\theta = 0.994$.

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To stabilise the volume mode σ, we include logarithmic redefinitions to $f(\sigma)$ resulting in

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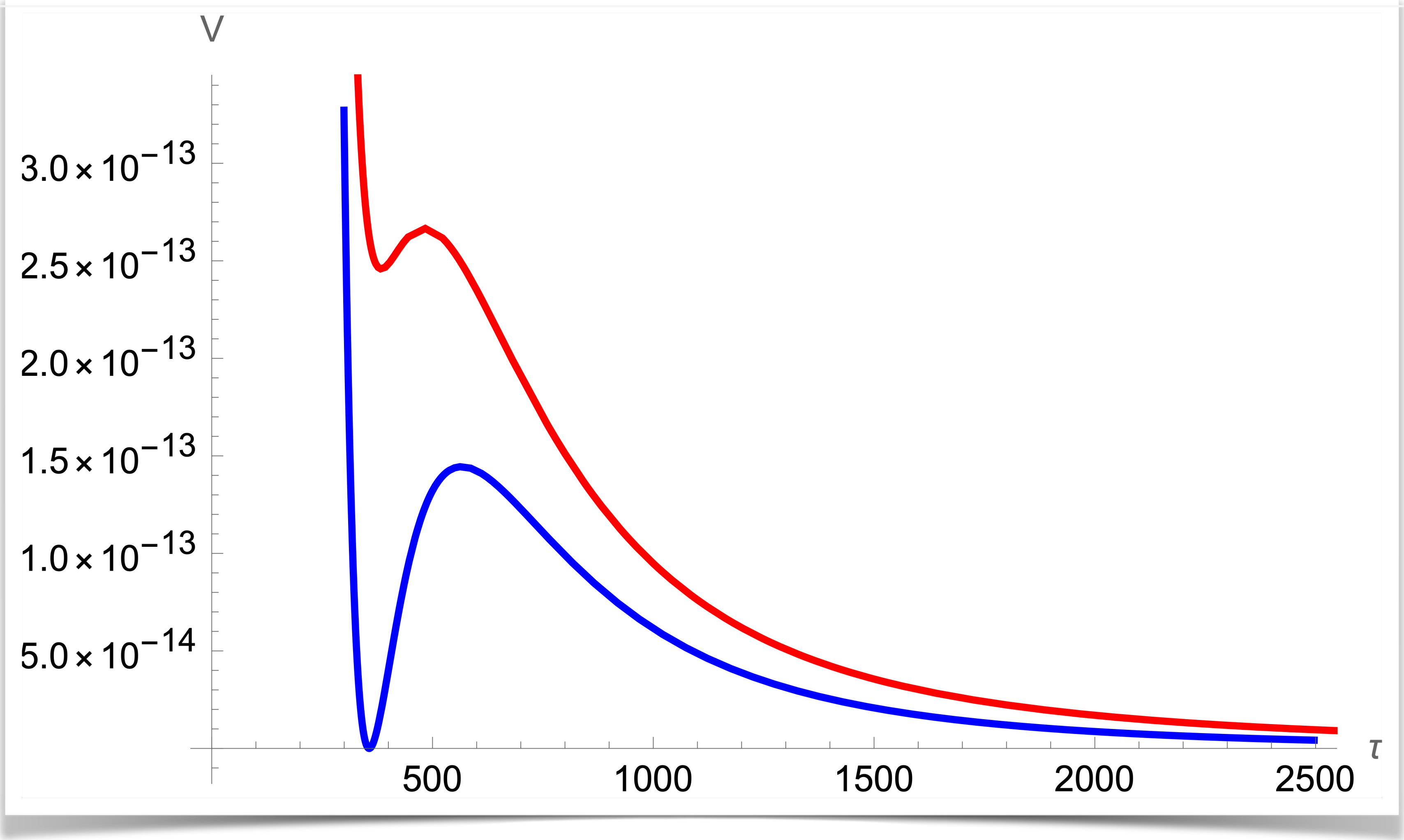

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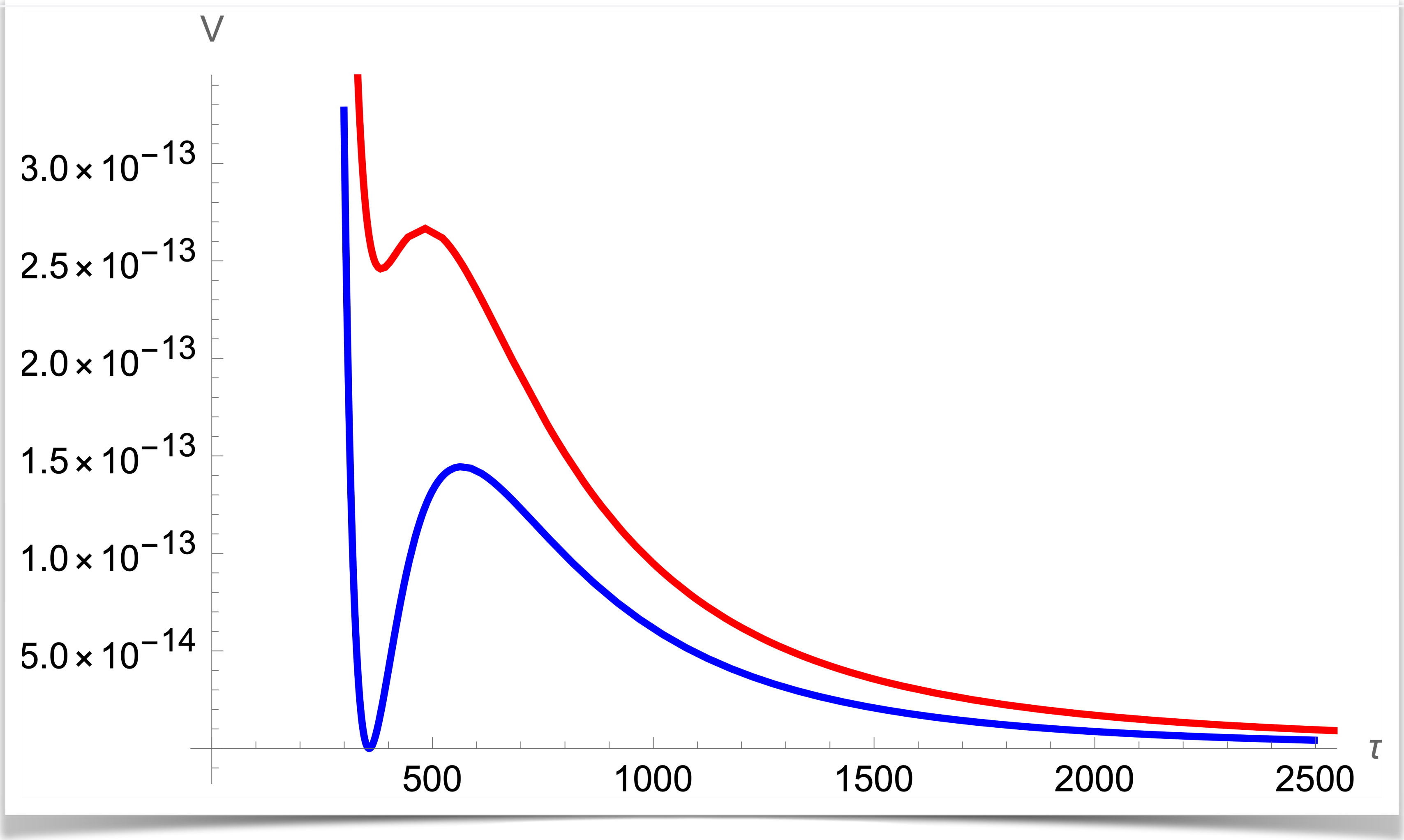

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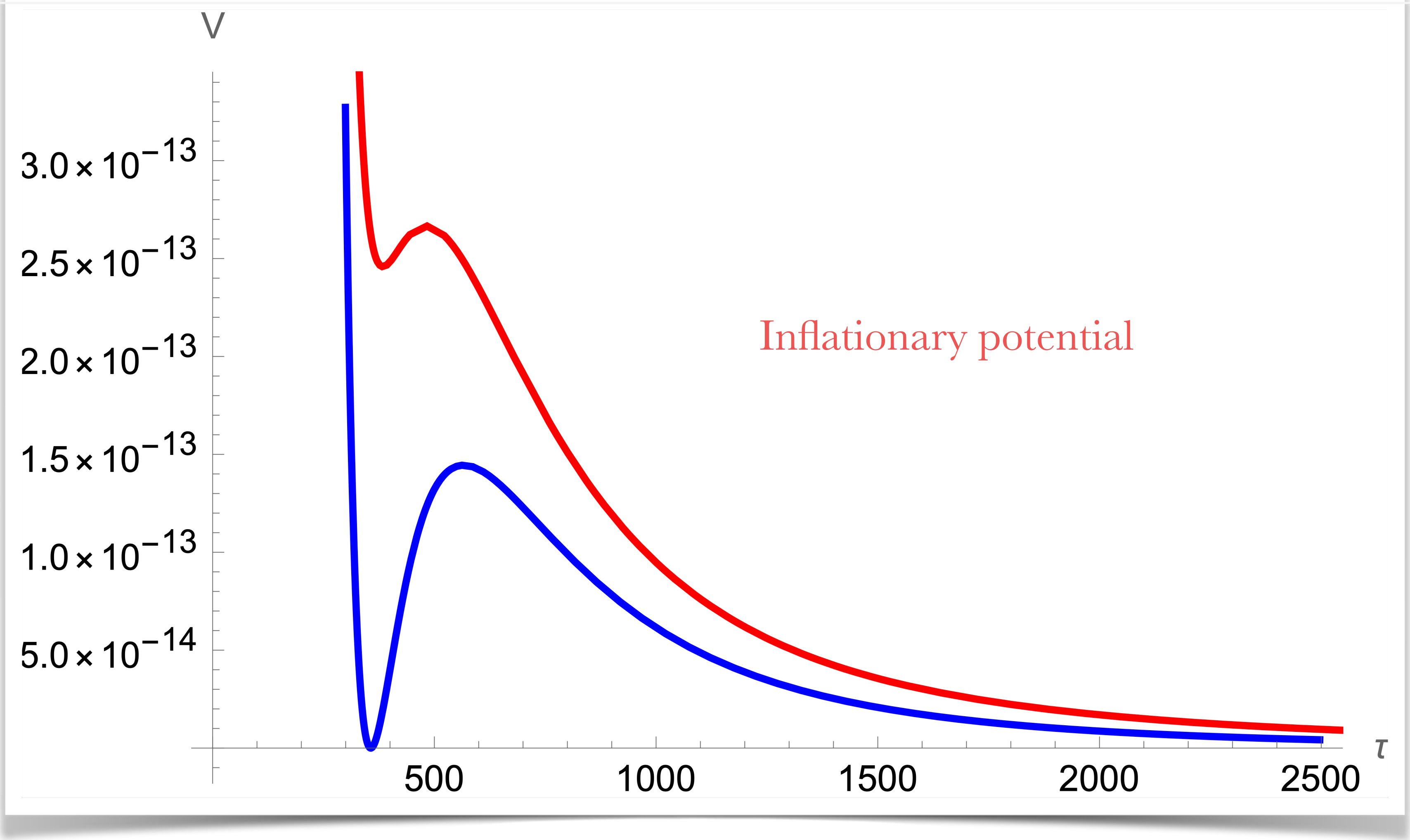

Figure: The parameters used to generate this plot are $\xi = g_s = 0.1$, $W_0 = 1$, $W_X^2 = 10^{-7}$ *and* $T_7 = 2\pi$, *with* $\theta = 0.994$.

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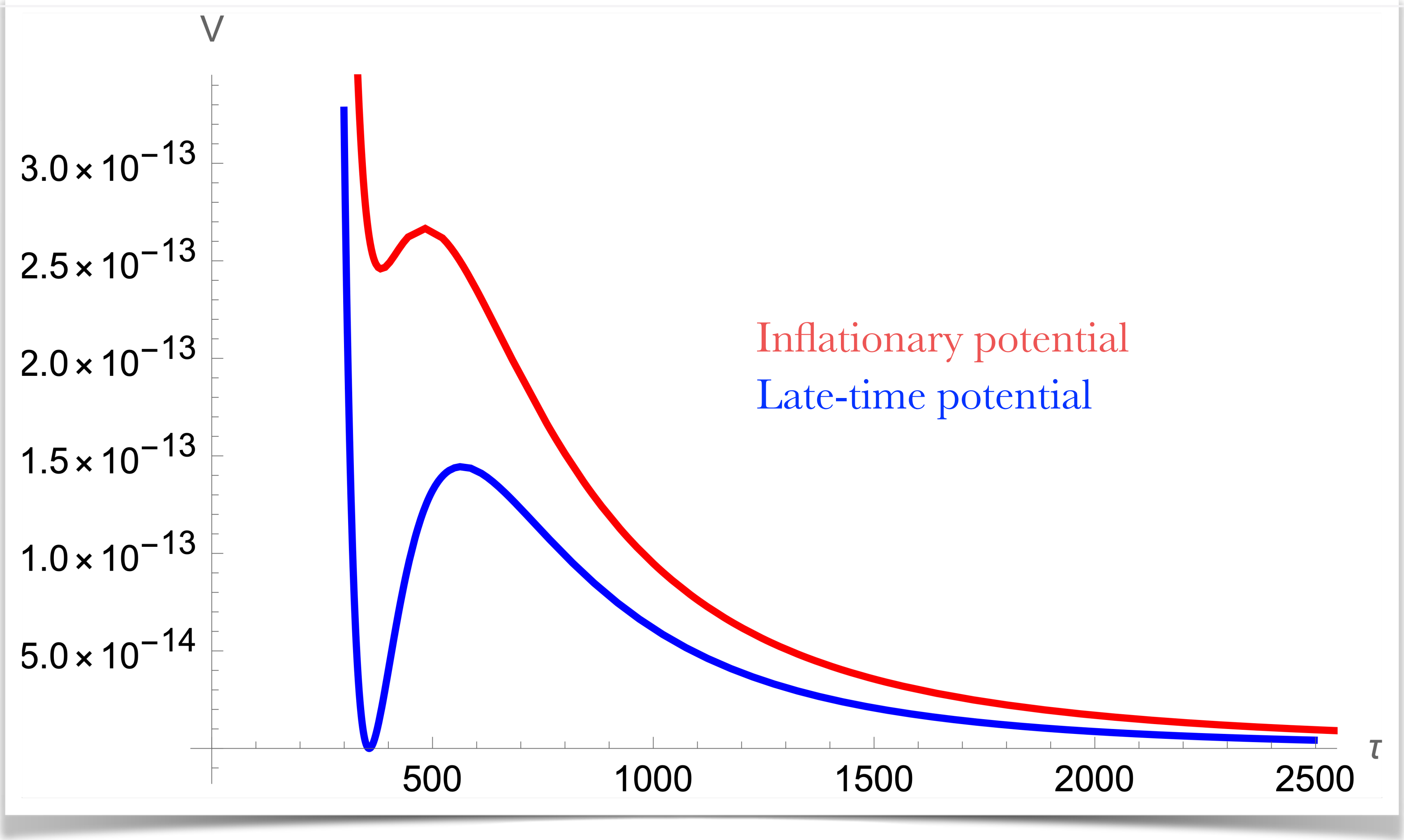

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$$\frac{27\,MK}{4(4\pi)^3\sigma_{\min}^3}\left(\sigma_{\min}\,e^{-4\rho}\right) \ll \left(\frac{\varphi}{M_p}\right)^4 < \frac{27\,MK}{4(4\pi)^3\sigma_{\min}^3}.$$

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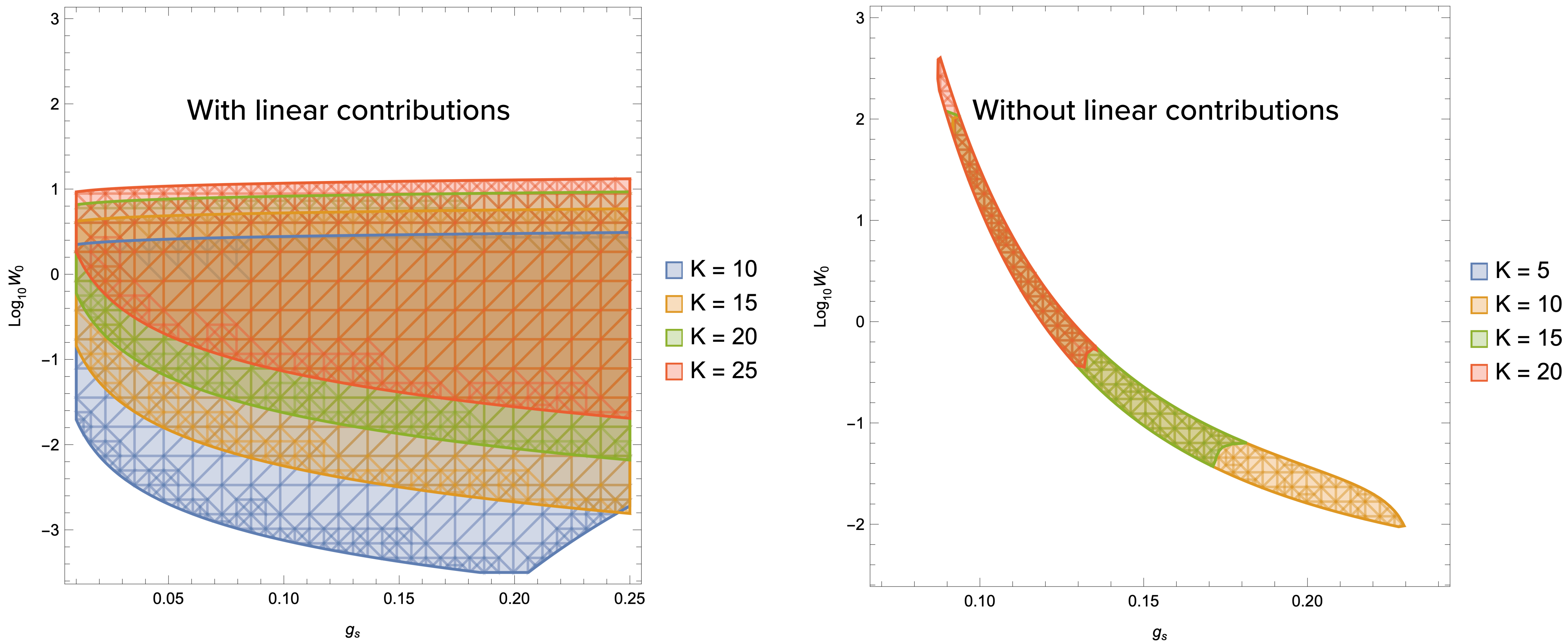

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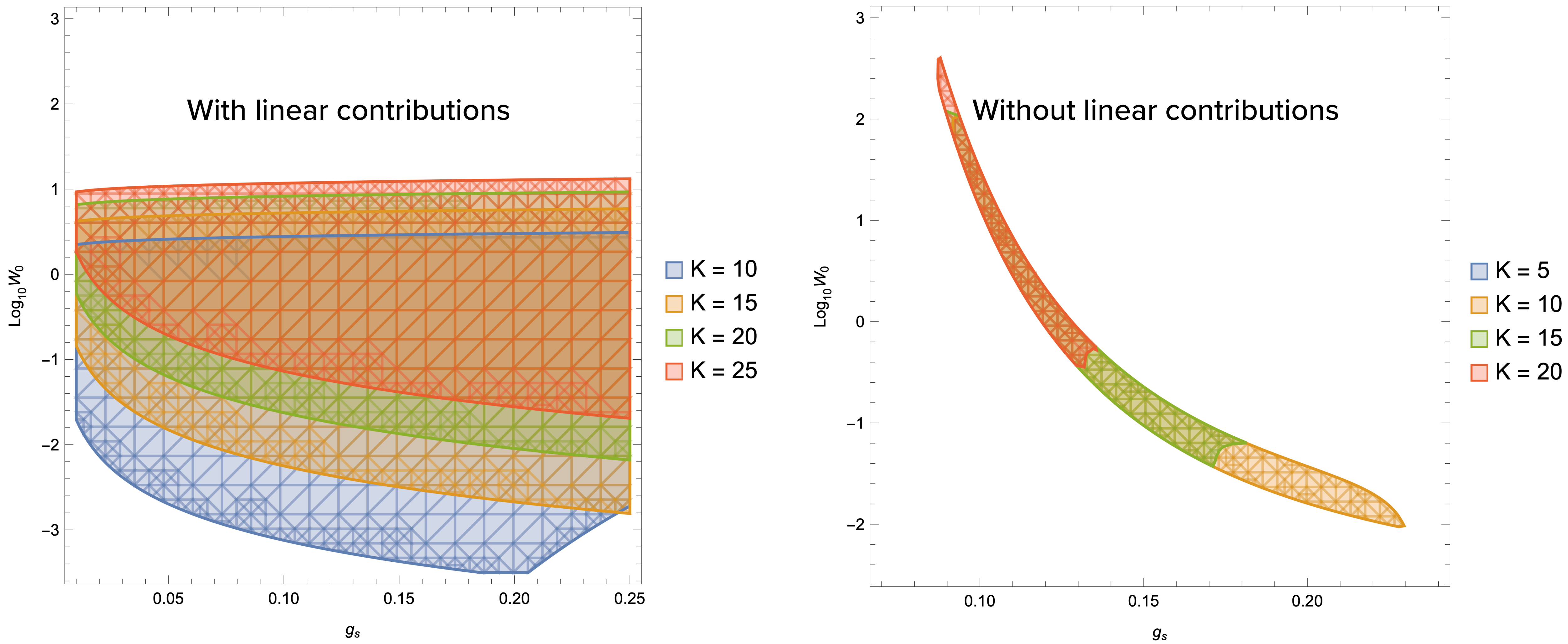

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“I am just a child who has never grown up. I still keep asking these 'how' and 'why' questions. Occasionally, I find an answer.”

-S. Hawking.

THANK YOU!

Mario Ramos Hamud
Email: mr895@cam.ac.uk
DAMTP | University of Cambridge

Backup slides

Modulus stabilisation

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String compactifications

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String compactifications

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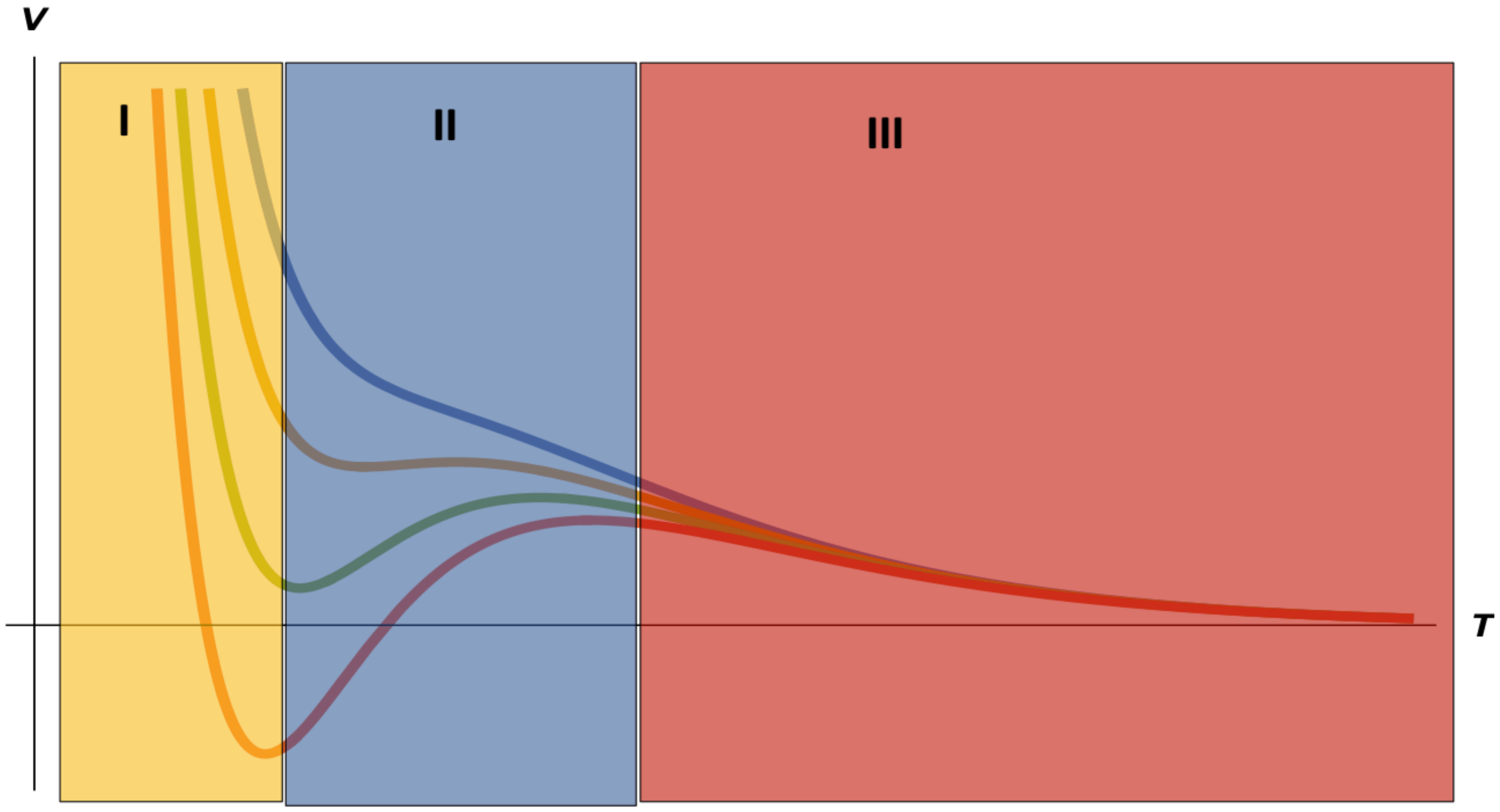

Modulus stabilisation

String compactifications

- The low energy effective action of string theories in 10d can be organised in a double expansion: the α' and g_s expansions. The six extra dimensions must be **compactified**.

- After compactification, a requirement that some supersymmetry is preserved implies that the internal manifold is a Calabi-Yau manifold with a characteristic **shape** and **volume**.

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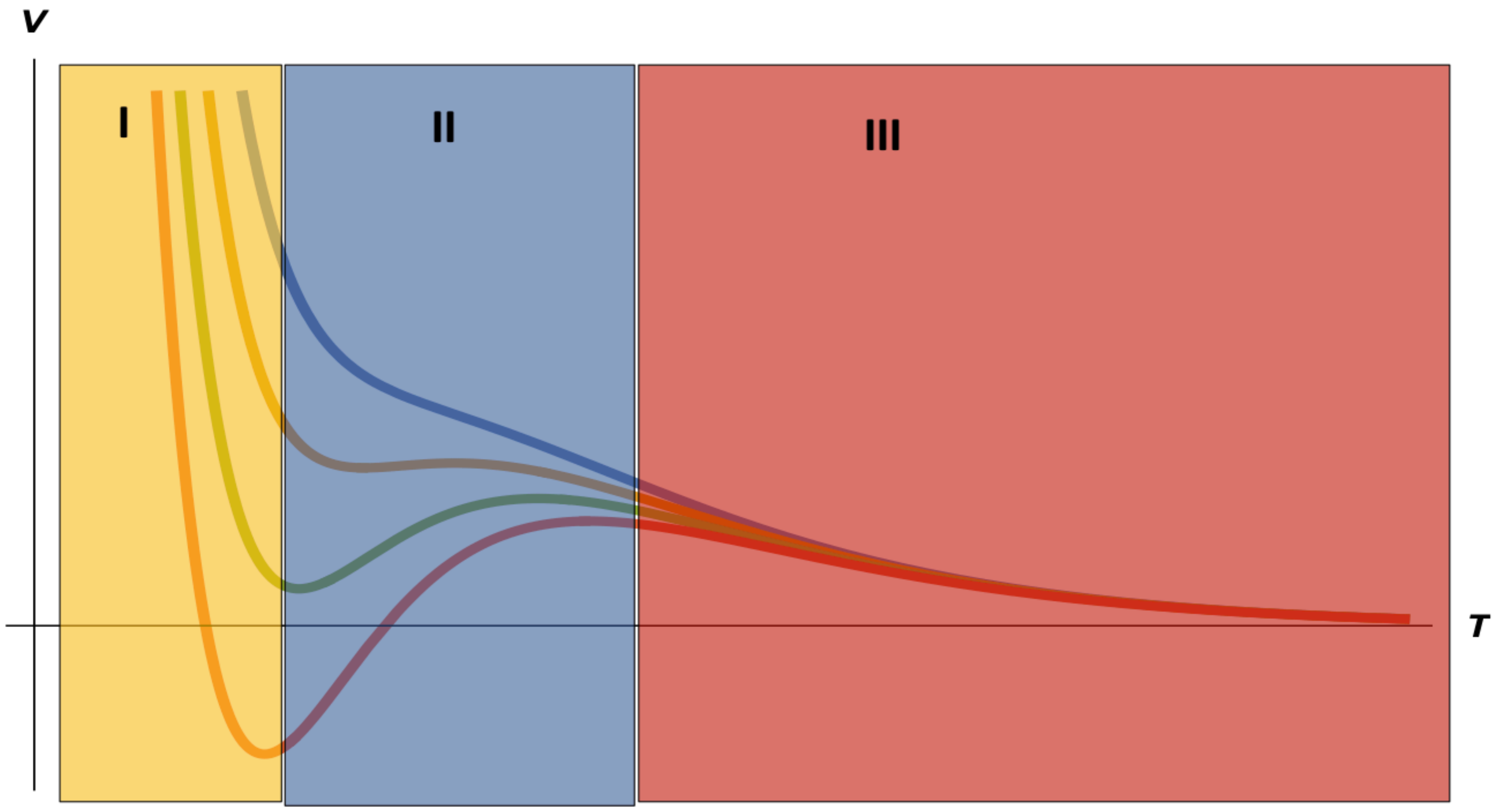

[F. Quevedo, 2022]

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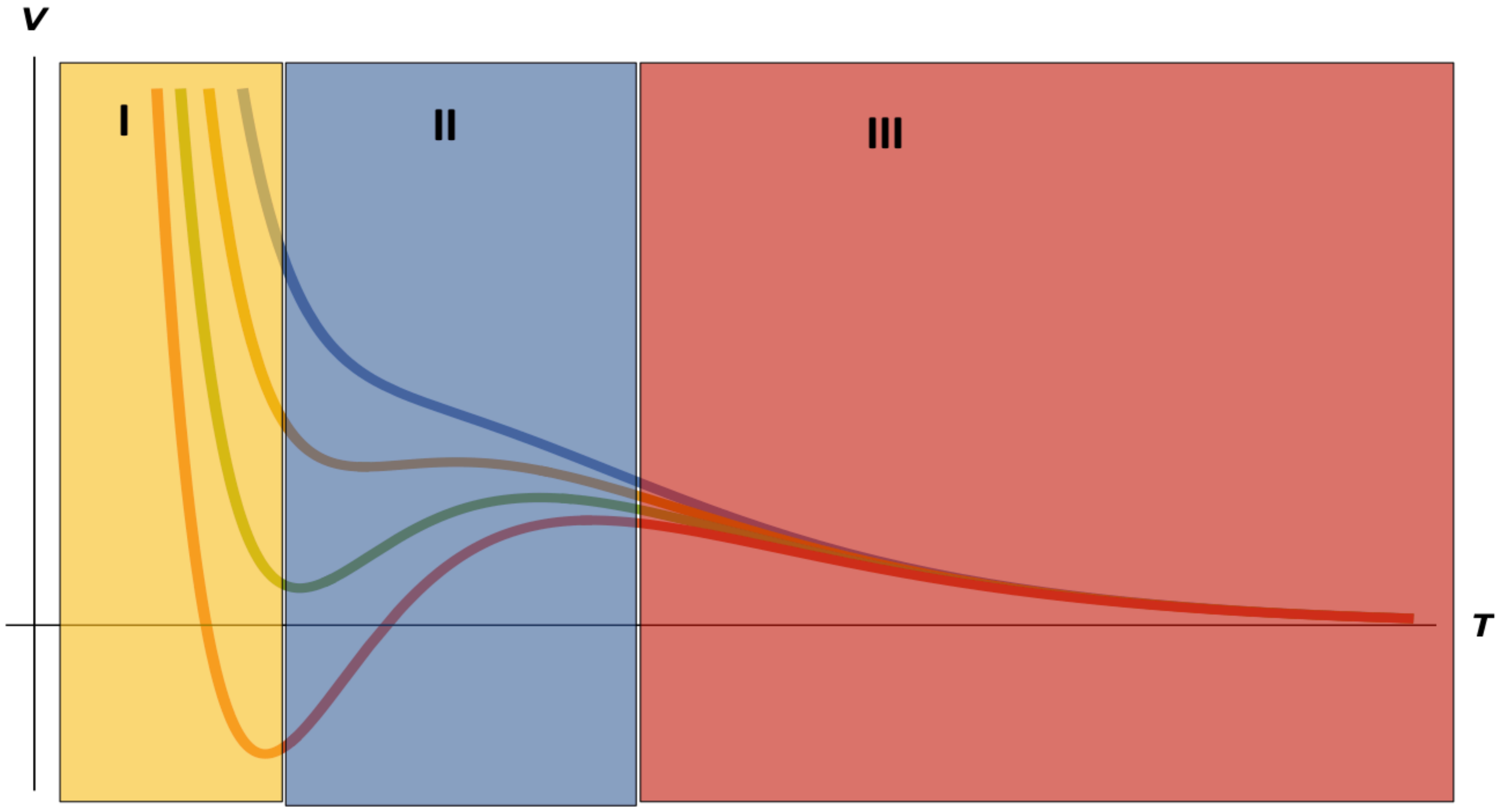

[F. Quevedo, 2022]

- Region I: out of the domain of parametric control of the EFT (small $\mathscr{V}$ / strong g_s).
- Region II: requires extra ingredients in the compactification to get a minimum.
- Region III: runaway region which is the only one fully trustable in the EFT.

If the scalar potential has a minimum, it is generically at $s \sim \tau \sim \mathcal{O}(1)$.

η-PROBLEM

Consider the Kähler potential

$$K \simeq -3\ln[\tau - \phi\bar{\phi} + \cdots].$$

when τ is fixed by **non-perturbative effects**, $\phi\bar{\phi}$ induces a correction to the inflaton potential given by

$$V_{\text{correction}} \sim \frac{V_{\text{original}}}{\tau^3}\phi\bar{\phi},$$

with V_{original} fixing the Hubble scale during inflation: $H_I^2 \sim \dfrac{V_{\text{original}}}{\tau^3}$.

- The mass contribution of the inflaton is $m_\phi^2 \sim \dfrac{V_{\text{original}}}{\tau^3} \sim H_I^2$
- Slow roll parameter: $\eta \sim \dfrac{V''}{V} \sim \dfrac{m_\phi^2}{H_I^2} \sim 1 \;\Rightarrow$ No longer slow-roll inflation!

η-problem can be avoided by doing a **perturbative stabilisation of the volume modulus.**

EXPERIMENTAL DATA

Compatibility with data

We use the Planck data for observational constraints on the amplitude of density perturbations and the spectral index n_s. It can be shown that CMB observations can be matched at horizon exit around $N_e = 56$ e-foldings before the end of inflation where:

$$V_{\text{inf}} \simeq 10^{-17} M_p^4, \quad \varphi_* = 10^{-3} M_p, \quad \text{and} \quad r \sim 2 \times 10^{-8},$$

with a tiny tensor-to-scalar ratio r that is far from the present observational reach.

The value of the scalar potential at horizon exit can be used to express ρ in terms of the other UV parameters → number of free parameters reduced to three: W_0, g_s and K.