Title: Cosmological Constraints and Fine-Tuning in Brane-antibrane Inflation Models

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Abstract: We systematically explore the parameter space of the state-of-the-art brane-antibrane inflation model (Baumann et al.) which is most rigorously derived from string theory, applying the COBE normalization and constraints on the spectral index. We define an effective volume in parameter space consistent with the constraints, and show that the fine tuning problem is this model is alleviated by four orders of magnitude for the optimal parameter values, relative to a fiducial point which has previously been considered. We also discuss the overshooting problem in this model which restricts the allowed initial conditions on the brane-antibrane separation, showing that the allowed region is expanded (by a factor of 5) when optimal model parameters are chosen. We point out a subtlety for getting correct predictions in the approximation of effective single field inflation, where the Kahler modulus is integrated out.

PASCOS 08

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How Delicate is Brane-Antibrane Inflation?

Cosmological Constraints and Fine-Tuning in Brane-Antibrane Inflation Models

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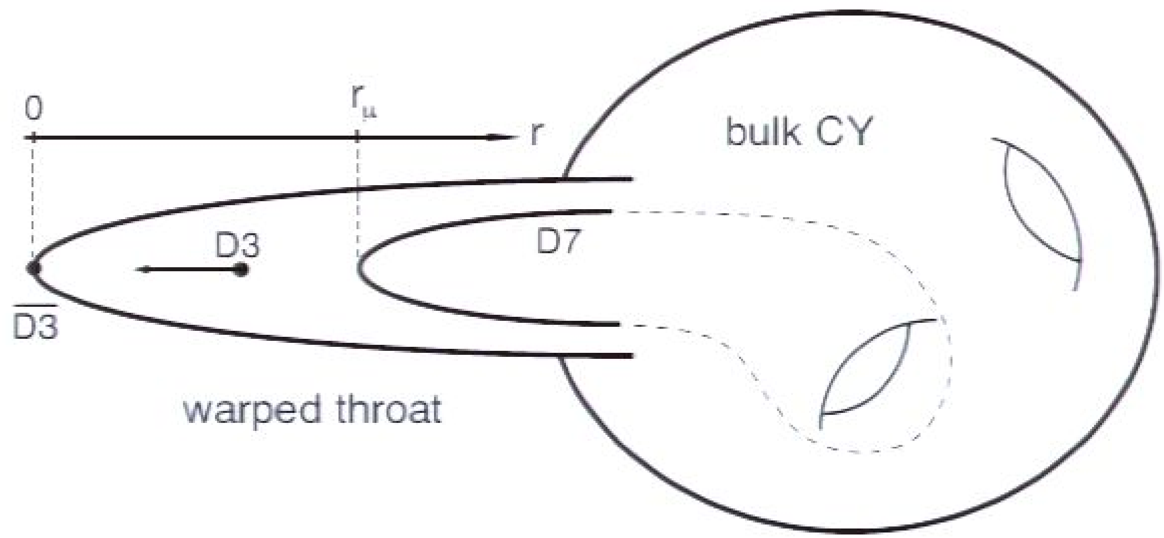
work in progress with James M. Cline

Outline

- Introduction.
- Baumann et al.'s model (2007).
- Fine-tuning $\Longrightarrow$ inflation.
- Alleviating the fine-tuning problem.
- Uplifting the potential and brane tension.
- Conclusions.

Brane-Antibrane Inflation

- An application of string theory to cosmology.
- Inflation: Brane and antibrane separated in an extra dimension. (Figure: Baumann et al. (2007).)



$$V(x,\omega) = V_F(x,\omega) + V_D(x,\omega).$$

A Delicate Universe

η-problem: $m_\phi^2 \sim H^2$, the potential is too steep for inflation.
V_F can be fine-tuned to give a sufficient flat potential (Baumann et al. (2007)):

$$
\begin{aligned}
V_F(x,\omega) &= \frac{a|A_0|^2}{3U^2} \mathrm{e}^{-2\omega} g^{2/n} \Big[2\omega + 6 - 2(2\omega_F + 3)\mathrm{e}^{\omega - \omega_F} g^{-1/n} \\
&\quad + \frac{3}{ng}\left(\frac{cx}{g} - x^{3/2}\right)\Big], \\
V_D(x,\omega) &= \frac{D(x)}{U^2}, \\
D(x) &= \frac{D_0}{1 + C_D \frac{D_0}{x^4}} + D_1.
\end{aligned}
$$

D_1: Contribution from anti-D3 branes in other throats.

Parameters

Ratio of V_D and V_F:

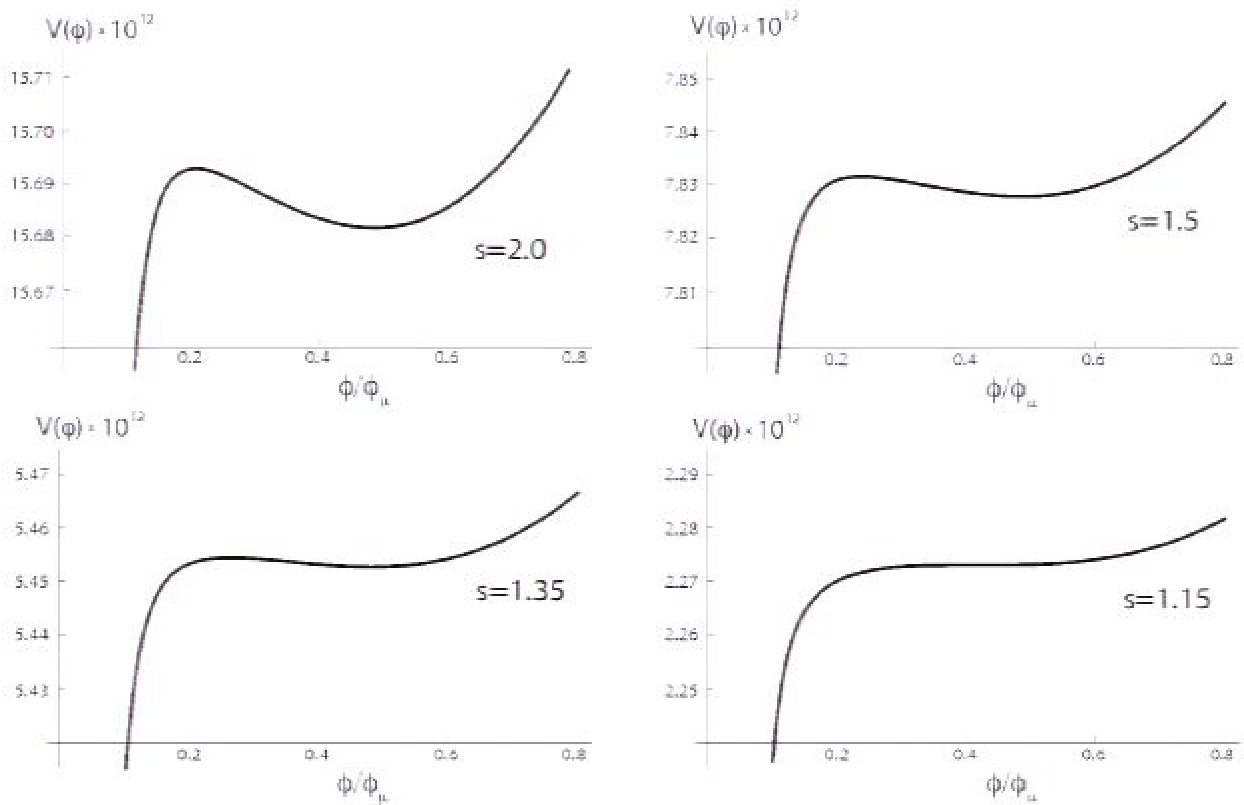
$$s \equiv \frac{V_D(0,\omega_F)}{|V_F(0,\omega_F)|} \qquad \Longrightarrow \qquad D_1 = \frac{2}{3} a |A_0|^2 s \omega_F \mathrm{e}^{-2\omega_F}.$$

Six independent parameters:

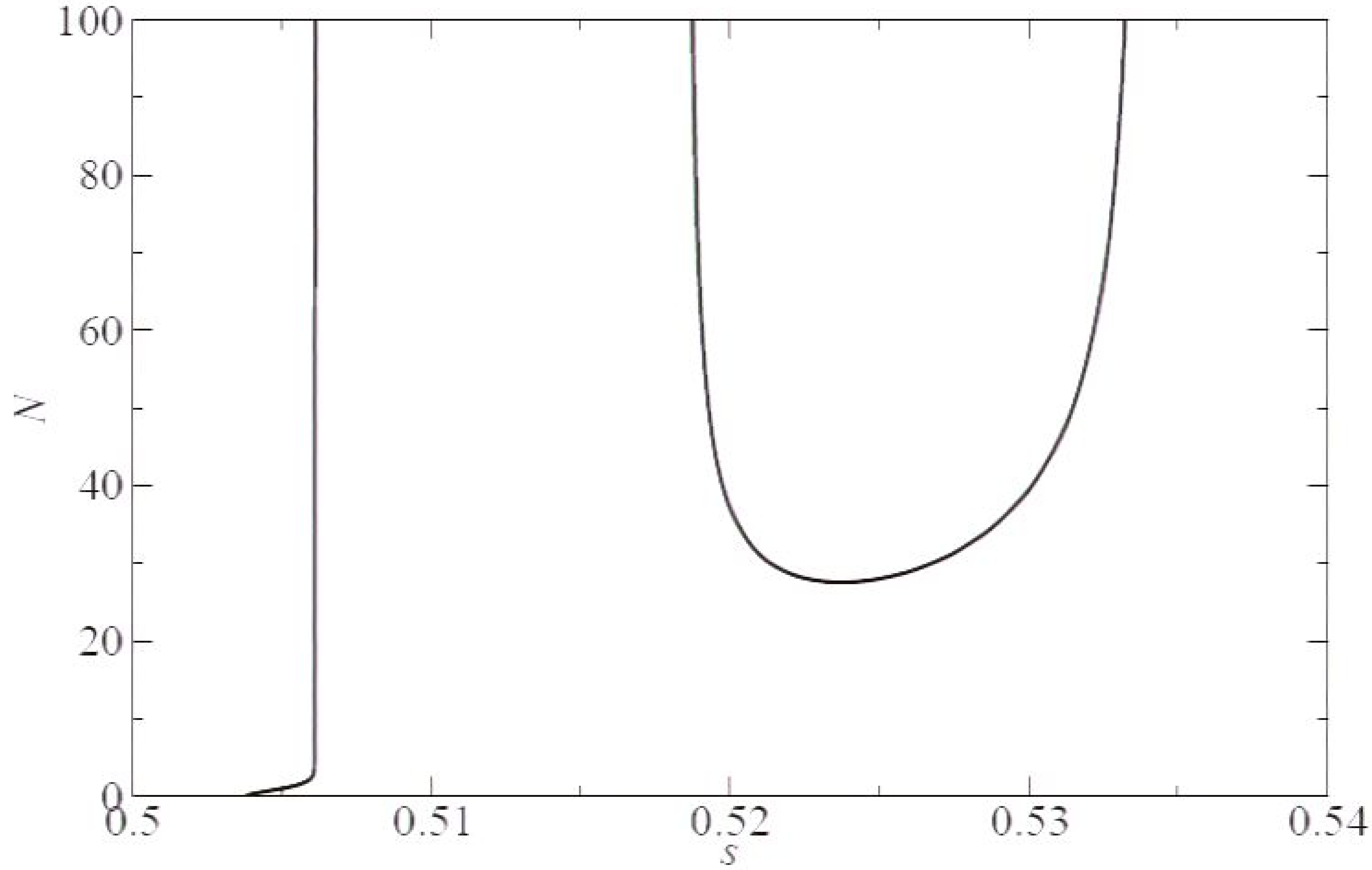
- s: $V_D/|V_F|$.
- A_0: prefactor of $W_{\rm np}$, normalization factor.
- D_{01}: D_0/D_1.
- ϕ_μ: location of D7 branes.
- ω_F: Kähler modulus before uplifting.
- n: the number of embedded D7 branes.

Inflation?

- $A_0 = 1, \phi_\mu = 0.241, \omega_F = 10.009, n = 8.$ $(D_{01} = 1.)$
- Effective single-field trajectory. (Baumann et al. (2007).)



Parameter Space – s



Cosmological Constraints

Enough e-foldings?

$\Longrightarrow$ uplifting the plateau.

Correct $\mathcal{P}_\mathcal{R}$ and n_s?

$\Longrightarrow$ tuning s can give

$$N \geq 50.$$

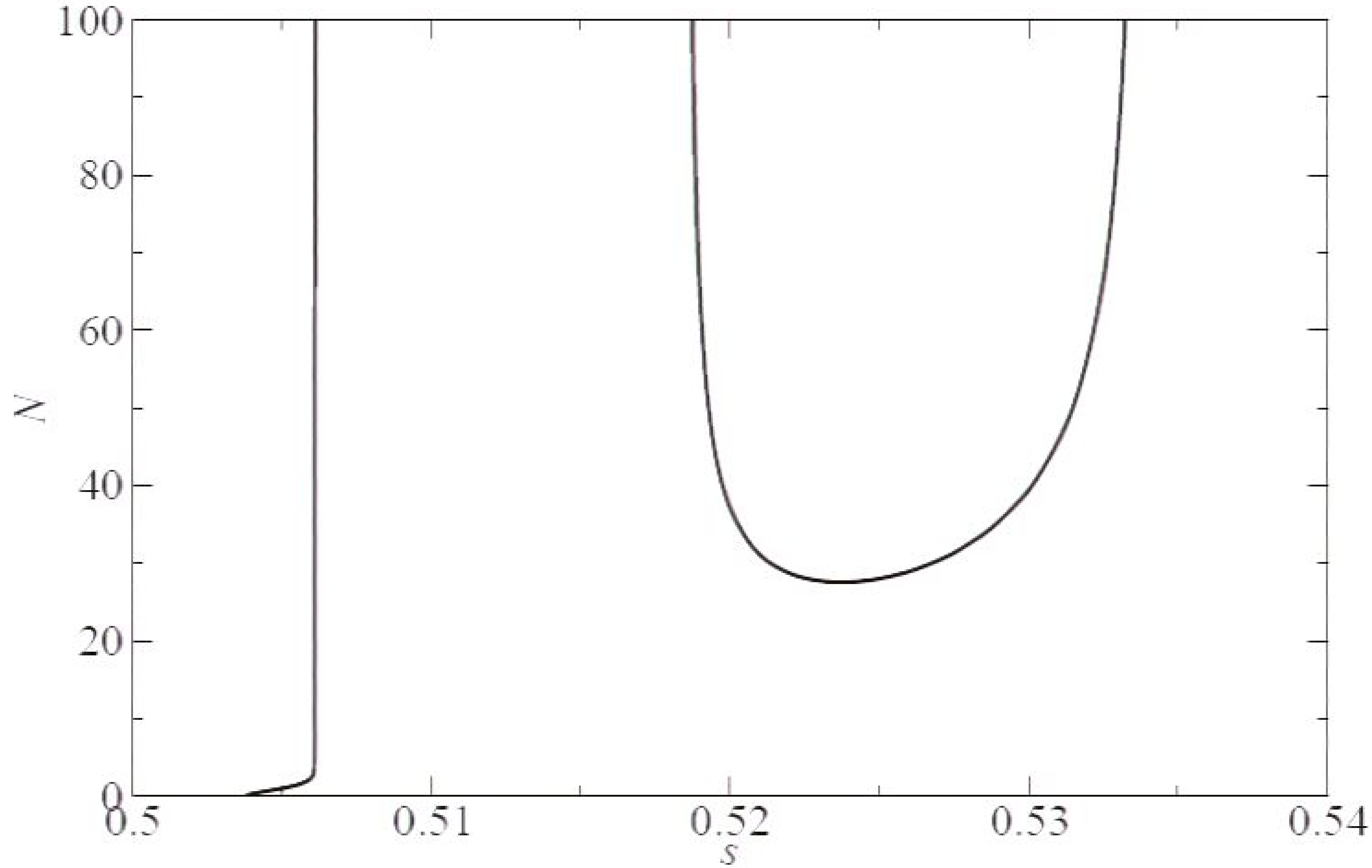
but not

$$\begin{aligned} \mathcal{P}_\mathcal{R} &\sim 2.4 \times 10^{-9}, \\ n_s &\sim 0.96. \end{aligned}$$

(Pandal et al. (2007))

$\Longrightarrow$ Need other parameters.

Parameter Space – s



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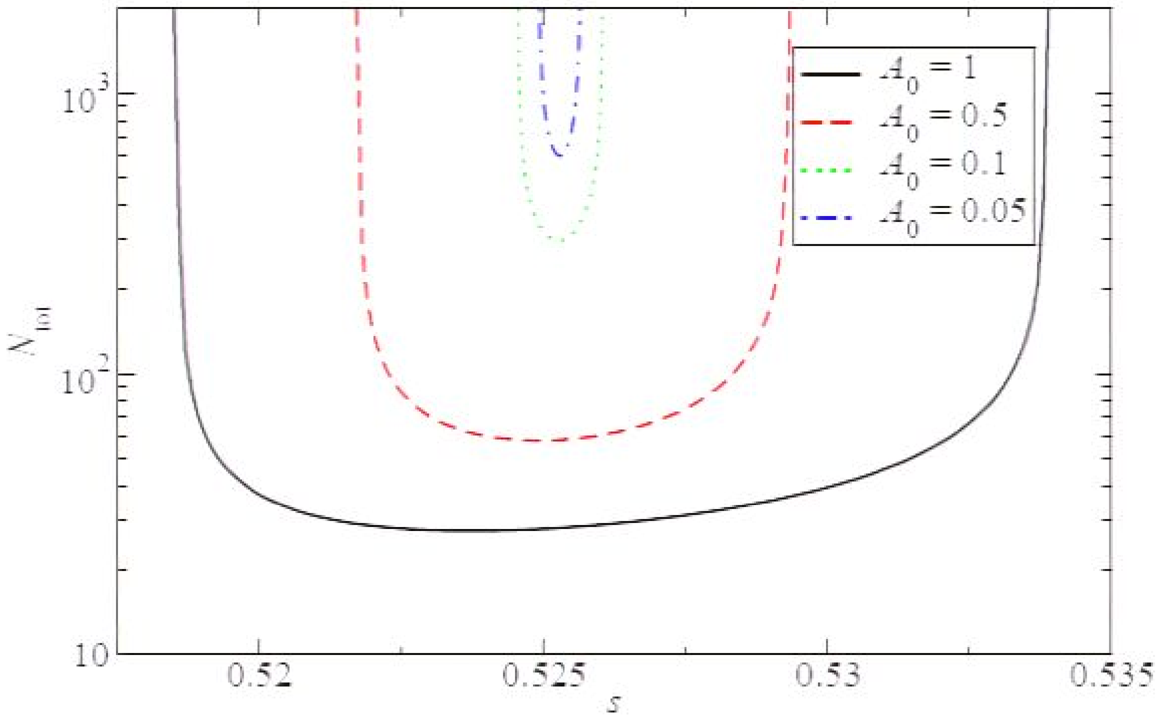
Normalization Factor: A_0



- COBE normalization $\rightarrow N \geq 50$.
- Fine-tuning $s \rightarrow$ monotonic potential.

Searching the Parameter Space

Find an optimal parameter regime which requires less fine-tuning.

Metropolis algorithm:

- Maximize objective function (allowed parameter space).
- Random steps (search in N dimensions).
- Control parameter T (temperature — anneal process).

Allowed parameter space:

$V(s_0)$ monotonic $\rightarrow V(s_0+\sigma_s/2)$ and $V(s_0-\sigma_s/2)$ monotonic.

One dimensional volume (width): σ_s.

N dimensional volume

$$V_N = \prod_i \sigma_i . \qquad \delta_N = \frac{V_N}{\prod_i p_i} . \qquad \delta'_N = \sqrt[N]{\delta_N} .$$

Parameter	V_6	δ_6	δ'_6
s, A_0	3×10^{-18}	4×10^{-17}	0.2%
s, A_0, D_{01}	3×10^{-17}	2×10^{-16}	0.2%
s, A_0, ϕ_μ	4×10^{-15}	1×10^{-13}	0.7%
s, A_0, n	3×10^{-13}	2×10^{-12}	1%
s, A_0, ω_F	0.2	8×10^{-7}	10%
$s, A_0, D_{01}, \phi_\mu, n, \omega_F$	0.7	1×10^{-6}	10%

Physical Model

- n integer: the number of embedded D7 branes.
- $A_0 < 1(M_{\rm Pl})$: gaugino condensation scale.

Parameter	V_5	δ_5	δ_5'
s, A_0	4×10^{-16}	4×10^{-14}	0.2%
$s, A_0, D_{01}, \phi_\mu, \omega_F$	0.07	2×10^{-5}	10%
$s, A_0(< 1), D_{01}, \phi_\mu, \omega_F$	1×10^{-8}	3×10^{-8}	3%

Alleviating fine-tuning: from 0.2% to 3% of each parameter.

Uplifting the Potential and Brane Tension

Uplifting the potential:

$$V(0, \omega_0) = 0.$$

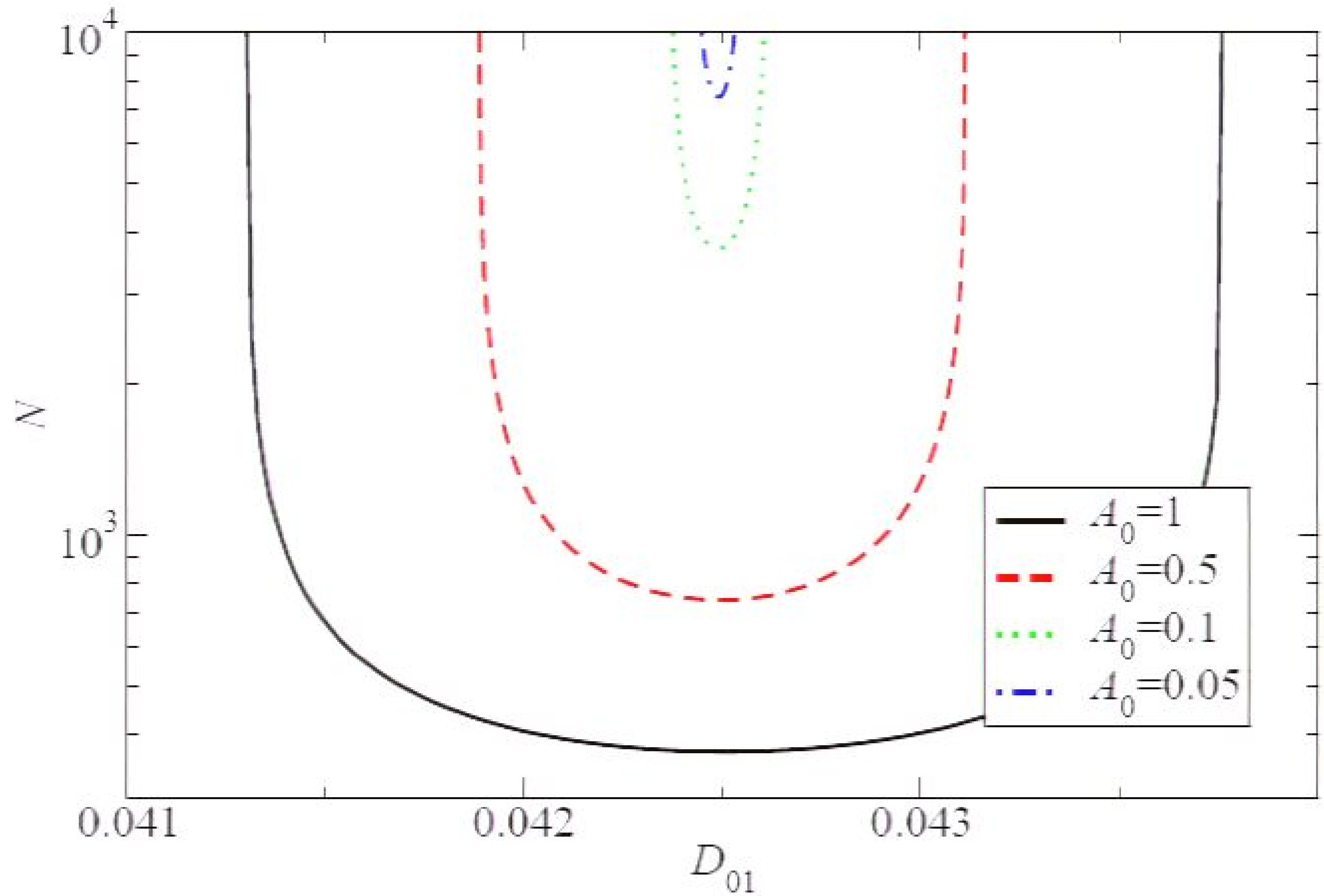
ω_0: stable value of ω at $x = 0$:

$$\frac{\partial}{\partial \omega} V \bigg|_{0, \omega_0} = 0.$$

$$\Longrightarrow s = \frac{2 + \omega_0}{\omega_F} e^{2\omega_F - 2\omega_0}.$$

The tension (D_1) from other anti-D3 branes at throats is fixed by uplifting.

Parameter Space – D_{01}



Work in progress.

Conclusions

- Brane-antibrane inflation can satisfy current cosmological constraints $(N, \mathcal{P}_{\mathcal{R}}, n_s)$.
- Needs fine-tuning.
- Allowed parameter volume is expanded by 10^6 for the optimal parameter values.
- The tension at $x = 0$ is fixed by uplifting: fine-tune D_0 instead of s (D_1).

Thanks!