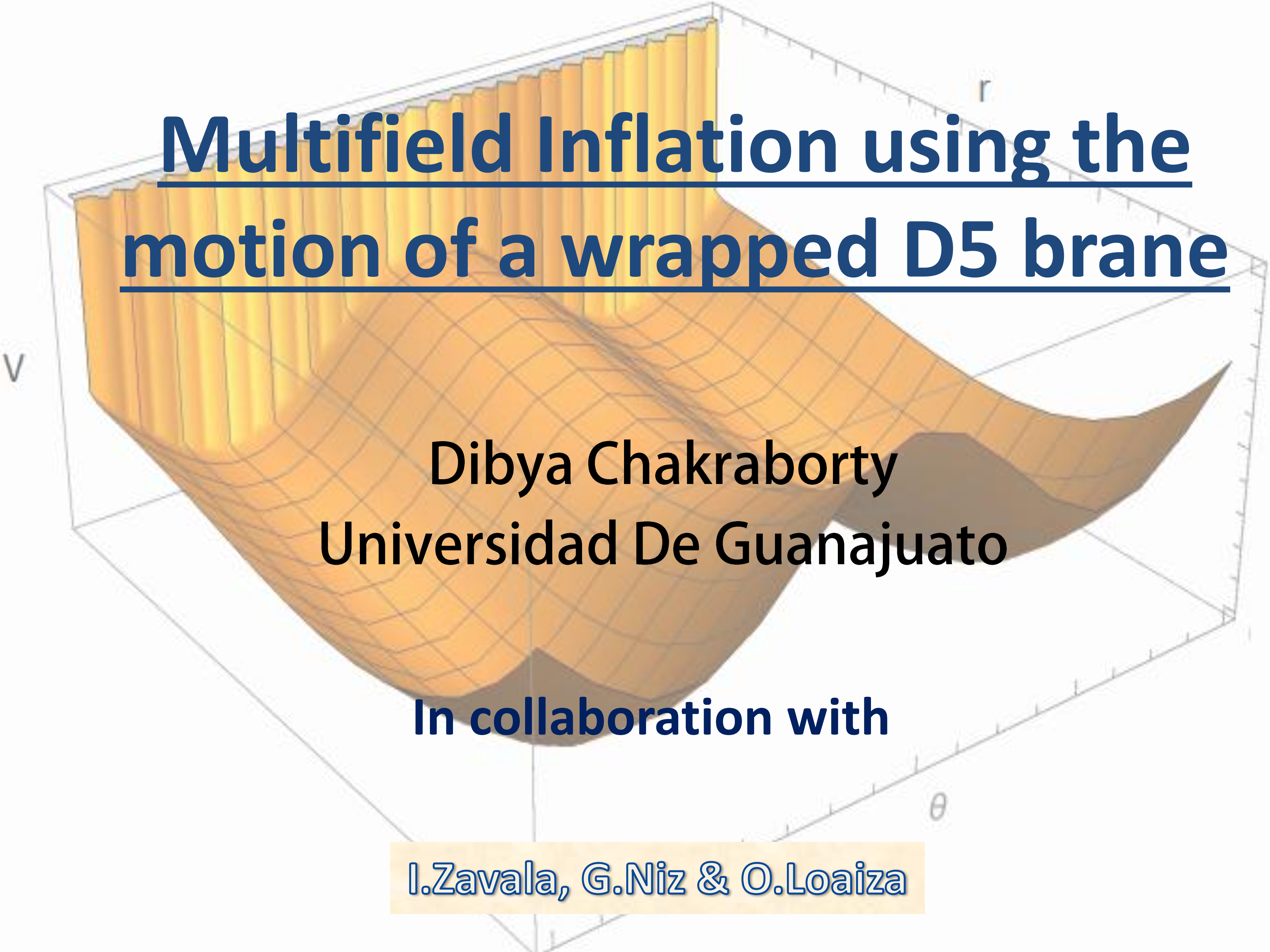
Multifield Inflation using the motion of a wrapped D5 brane



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In collaboration with

I.Zavala, G.Niz & O.Loaiza

Outline

- The physics behind?
- The motivation
- The main setup
- Inflating with branes
- Observables
- Discussions
- Outlook

Reference: Zachery kenton & ThomasarXiv:1409.1221v3

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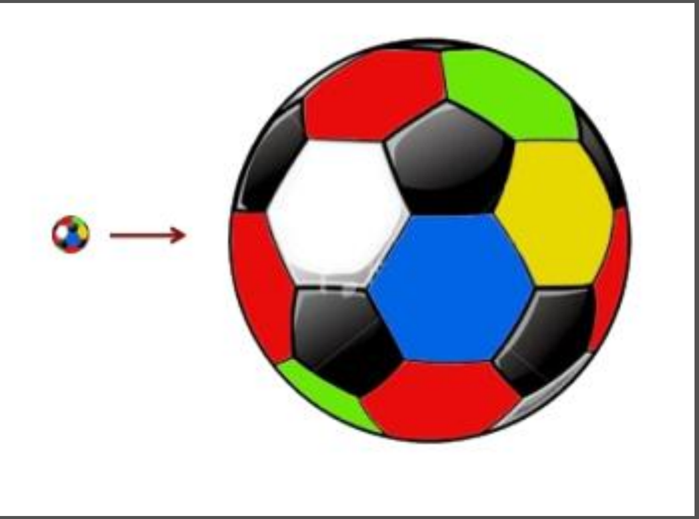
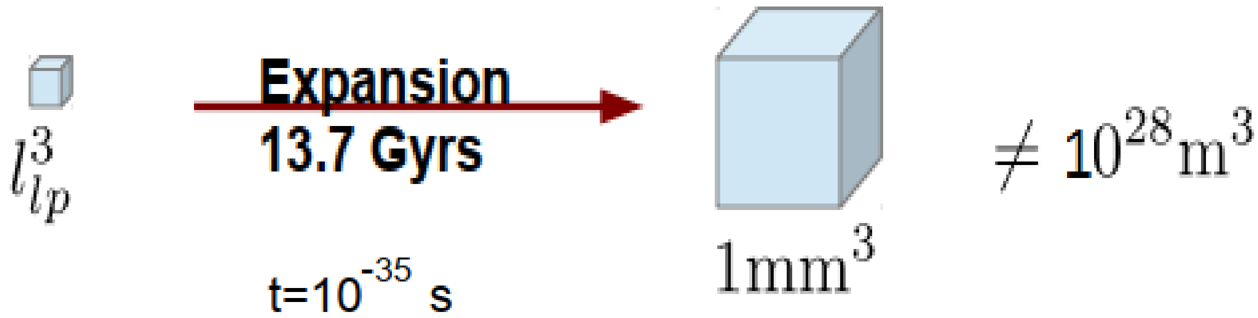
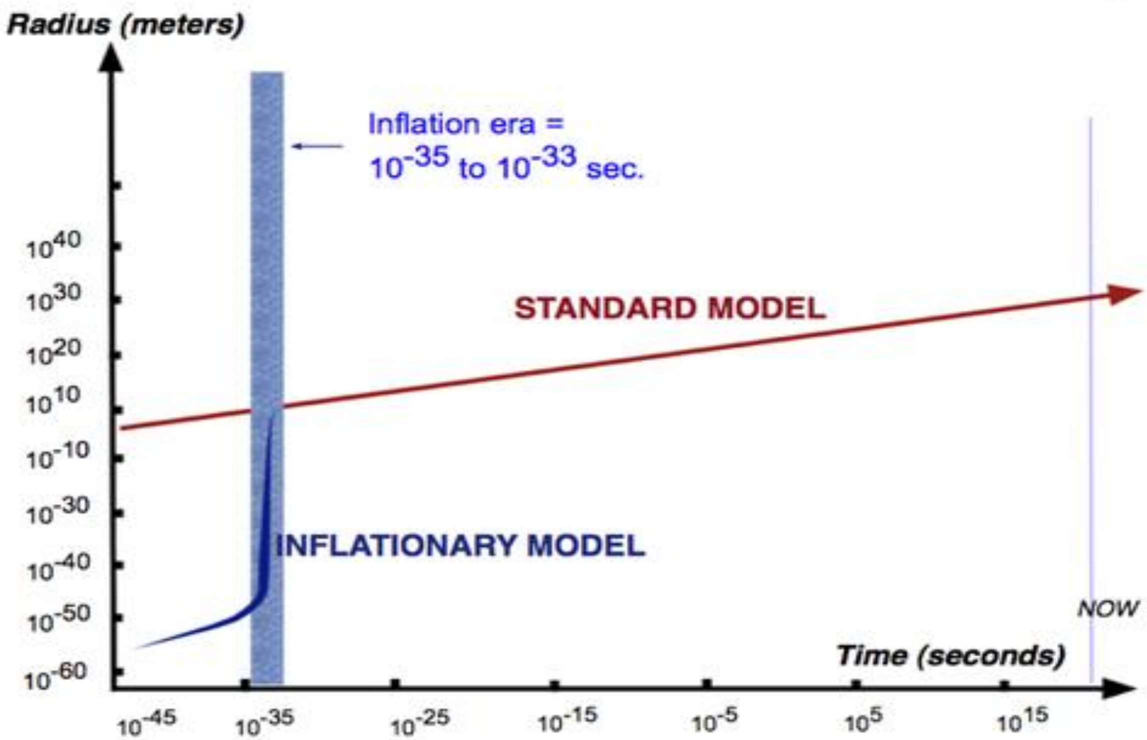
INFLATION

The period of accelerated expansion(Exponential) of early universe



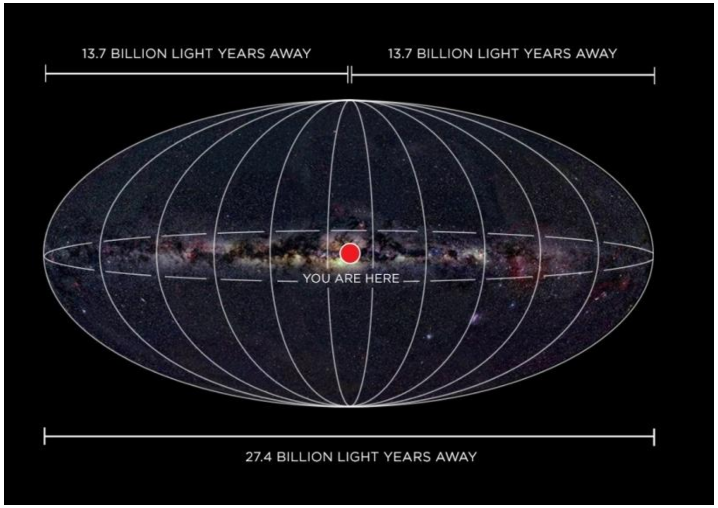




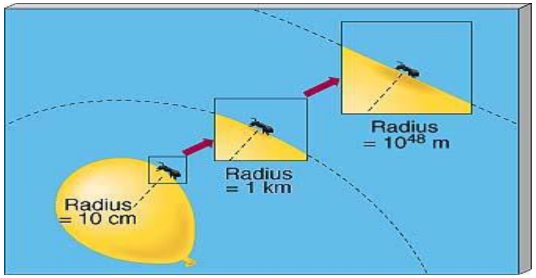
EXPANSION OF THE OBSERVABLE UNIVERSE

Problems of SBB model

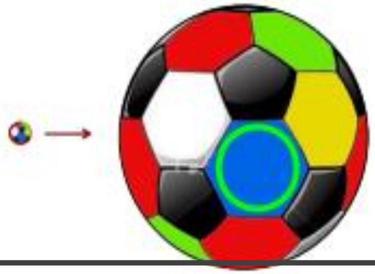
1) The Horizon problem



2) The flatness problem



3) Magnetic monopoles $\longrightarrow$ Dilutes them



Inflationary mechanism

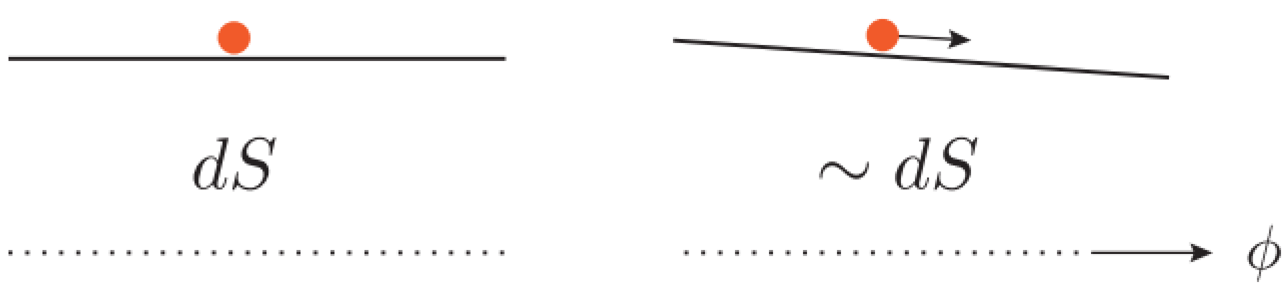
A period of **accelerated expansion(Quassi-exponential).**

Homogeneity and isotropy implies FRW metric:

$$\mathrm{d}s^2 = -\mathrm{d}t^2 + a^2(t)\,\mathrm{d}\boldsymbol{x}^2$$

Which from the Friedmann equation we get,

$$\frac{\ddot{a}}{a} = (H^2 + \dot{H}) > 0 \quad \Rightarrow -\frac{\dot{H}}{H^2} < 1 \qquad H = \frac{\dot{a}}{a}$$

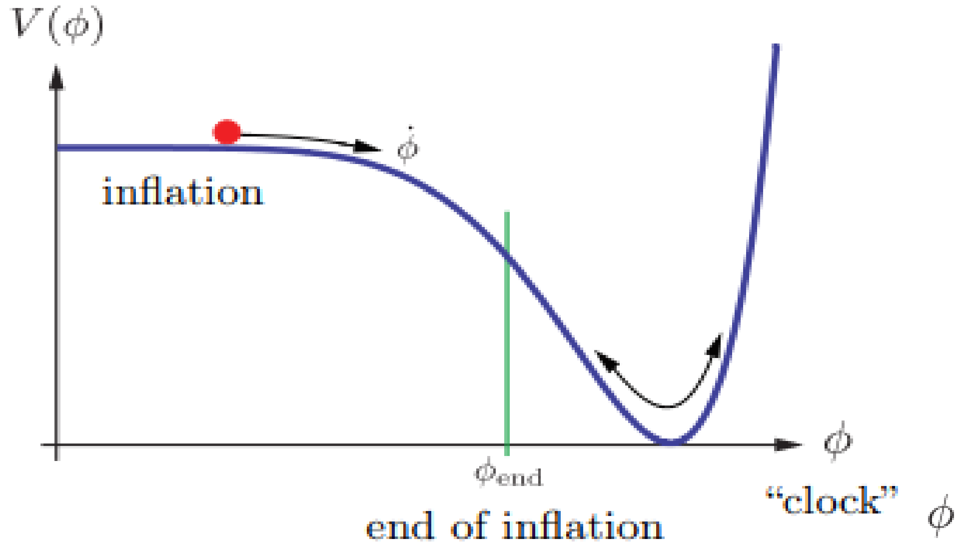


"de-Sitter with a clock"

Single field inflationary model

canonical scalar field slowly rolling down a potential

$$S = \int d^4x \sqrt{-g} \left[\frac{M_{\rm pl}^2}{2} R - \frac{1}{2} g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi - V(\phi) \right]$$



Friedmann equation and scalar field equation reads

$$H^2 = \frac{1}{3m_{pl}^2}\left[\frac{1}{2}\dot{\phi}^2 + V(\phi)\right],\ \ddot{\phi} + 3H\dot{\phi} = -V'(\phi)$$

Slow-roll essentially means,

$$KE \ll V \longrightarrow \boxed{\dot{\phi}^2 < V} \longrightarrow \boxed{\ddot{\phi} < H\dot{\phi}}$$

Which implies the following solution:

$$a(t) = a(t_0)\,\mathrm{Exp}\left[\int_{t_0}^{t} H dt\right] \sim a(t_0)e^{Ht}$$

In order to solve the Horizon problem inflation should last N=50-60

$$N(t) = \ln[a(t_{end})/a(t_{start})]$$

Slow roll parameters

$$\varepsilon \equiv -\frac{\dot{H}}{H^2} < 1 \quad , \qquad |\eta| \equiv \frac{|\dot{\varepsilon}|}{H\varepsilon} \ll 1$$

Taking N as the time variable

$$\epsilon = -\frac{\dot{H}}{H[t]^2} = -\frac{H'[N]}{H} \qquad \eta = (\phi')^2 - \frac{\phi''}{\phi'}$$

The potential slow roll parameter is as follows

$$\epsilon \equiv \frac{M_{\rm pl}^2}{2}\left(\frac{V'}{V}\right)^2 < 1 \quad \text{and} \quad \eta \equiv M_{\rm pl}^2 \frac{V''}{V} < 1$$

Two of the most robust predictions of inflation are a nearly scale invariant spectrum of density perturbations, encoded in the **spectral index or tilt *ns***, and a stochastic background of gravitational waves, encoded in the **tensor-to-scalar ratio *r***.

$$n_s - 1 = -3\left(1 + \frac{p}{\rho}\right) - \frac{d}{dN}\ln\left(1 + \frac{p}{\rho}\right) - \text{other}$$

arXiv:hep-th/9904176 Mukhanov

$$r = 16\epsilon$$

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¿ **Whys**?

¿ Whys?

I. Why string inflation?

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Super-Planckian field

$$\frac{\Delta\phi}{M_{\rm pl}} = \mathcal{O}(1) \times \left(\frac{r}{0.01}\right)^{1/2}$$

=

Requires a theory of QG: Inflation in string theory

¿ Whys?

I. **Why string inflation?**

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II. **Why beyond single field?**

¿ Whys?

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II. Why beyond single field?

III. Why branes? What type of brane?

¿ Whys?

I. Why string inflation?

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Requires a theory of QG: Inflation in string theory

II. Why beyond single field?

III. Why branes? What type of brane?

The position of the Dp brane in the extra dimension can play the role of inflaton in 4d physics.

D5?D3?D7?

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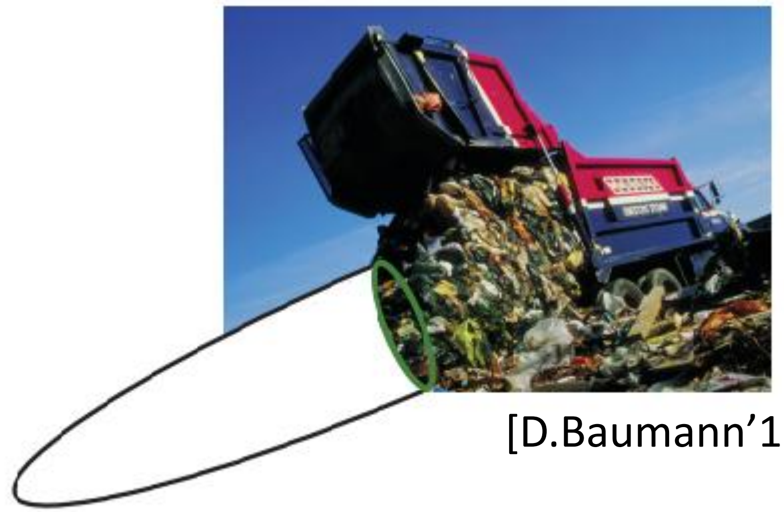
Unwarped-background geometry

We will consider Warped throat approximation which is a non-compact region of compact CY3

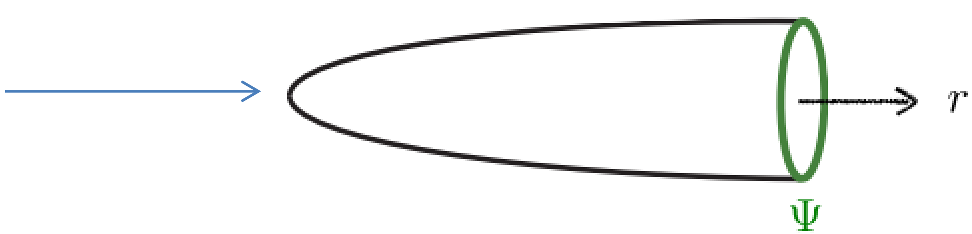


[D.Baumann’15]

Consider the six-dimensional CY cone defined by $\sum_{A=1}^{4} z_A^4 = 0$

$T^{1,1} \sim S^2 \times S^3$

Singularity



$$\mathrm{d}s^2 = \mathrm{d}r^2 + r^2 \mathrm{d}\Omega^2_{T^{1,1}}$$

The metric for the $T_{1,1}$ space is as following,

$$ds^2_{T_{1,1}} = \frac{1}{9}\left(d\psi + \sum_{n=1}^{2} \cos\theta_i d\psi_i\right)^2 + \frac{1}{2}\sum_{n=1}^{2}\left(d\theta_i^2 + \sin\theta_i^2 d\phi_i^2\right)$$

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Need Smoothing!!

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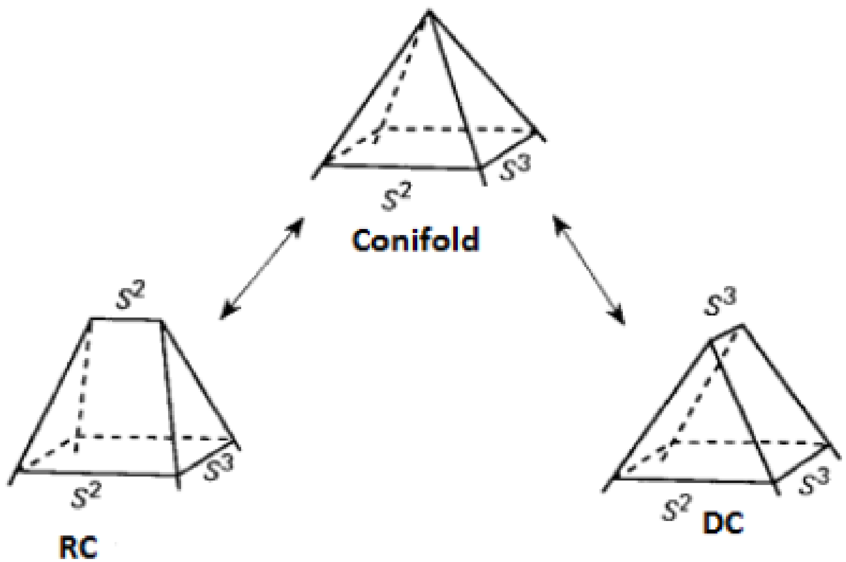
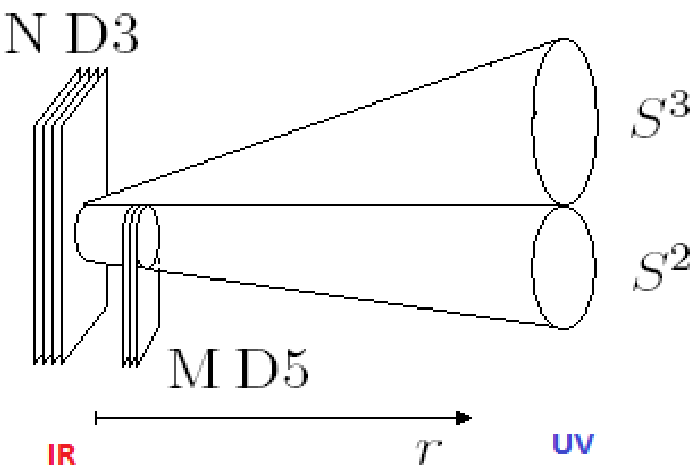
Need Smoothing!!

Resolution of the conifold singularity. [RC]



Deformation of conifold[DC]

Warped-background geometry

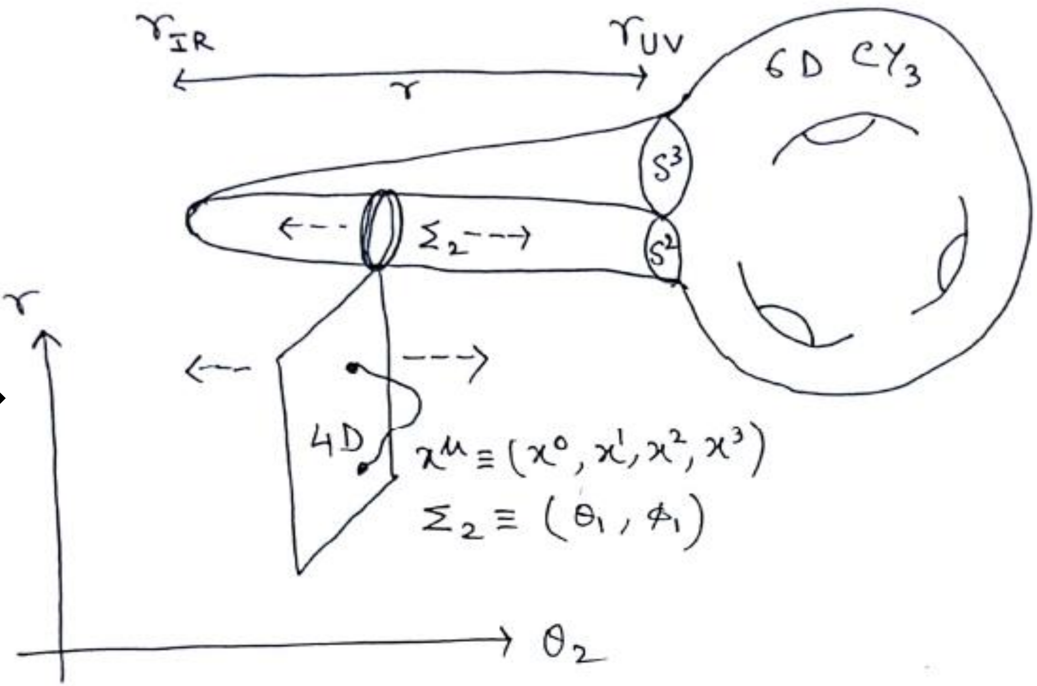


$S^3 : (\psi, \theta_2, \phi_2)$

$y^m = (r, \psi, \theta_1, \phi_1, \theta_2, \phi_2)$

$S^2 : (\theta_2, \phi_2)$

D5
Brane
set up



The metric for the RC is the following

$$ds^2_{RC} = \tilde{g}_{mn} dy^m dy^n = \frac{r^2 + 6u^2}{r^2 + 9u^2} + \frac{1}{9}\left(\frac{r^2 + 9u^2}{r^2 + 6u^2}\right) r^2 (d\psi + \cos\theta_1 d\phi_1 + \cos\theta_2 d\phi_2)^2$$

$$+ \frac{1}{6} r^2 (d\theta_1^2 + \sin^2\theta_1 d\phi_1^2) + \frac{1}{6}(r^2 + 6u^2)(d\theta_2^2 + \sin^2\theta_2 d\phi_2^2)$$

[L. A. P. Zayas and A. A. Tseytlin, *3-branes on resolved conifold*, *J. High Energy Phys.* **2000**]

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The local source term in type-IIB Sugra action for D-branes looks like;

$$S_{D5} = S_{DBI-D5} + S_{CS-D5}$$

$$S_{D_p} = -T_p \int d^{p+1}\varepsilon \sqrt{\gamma_{ab} + F_{ab}} + T_p \int C_{p+1}$$

Worldvolume flux

$$T_p = \left[(2\pi)^p g_s (\alpha')^{\frac{p+1}{2}} \right]^{-1}$$

$$\gamma_{ab} = \frac{\partial X^M}{\partial \varepsilon^a} \frac{\partial X^N}{\partial \varepsilon^b} \gamma_{MN}$$

Action for D5-brane

The total action of the local sources

$$= -T_5 \int_{W5} d^6\xi \sqrt{-det(P_6[g_{MN} + B_{MN} + 2\pi\alpha' F_{MN}])} + T_5 \int_{W5} d^6\xi P_6[C_6 + C_4 \wedge (B_2 + 2\pi\alpha' F_2)]$$

Pullback to the brane worldvolume

$$T_5 = [(2\pi)^5 g_s l_s^6]^{-1}$$

The pullback will is calculated from the metric ansatz [arXiv:hep-th/0701064]:

$$ds^2 = \mathcal{H}^{-1/2}(\rho, \theta_2) ds^2_{\mathrm{FRW}} + \mathcal{H}^{1/2}(\rho, \theta_2) ds^2_{RC}$$

After further simplification;

$$S = \int_{M_4} d^4 x a^3 [4\pi p T_5 \mathcal{F}^{\frac{1}{2}} (\frac{1}{2} v^2) - 4\pi p T_5 \mathcal{H}^{-1} (\mathcal{F}^{\frac{1}{2}} - \pi l_s^2 q)]$$

Co-efficient of Kinetic term-Field metric

Non-cancellation of DBI and CS

$$\mathcal{F}(r,\theta) = \frac{\mathcal{H}}{9}(r^2 + 3u^2)^2 + (\pi\alpha' q)^2$$

Resolution parameter, length of the throat for WRC

The poisson's equation on RC is as follows,[arXiv:1409.1221v3]

$$\tilde{\nabla}^2\Phi_- = \mathcal{R}_4 + \frac{\mathcal{H}^{-2}}{6\mathrm{Im}\tau}|G_-|^2 + \mathcal{H}|\partial\Phi_-|^2 + 2\kappa_{10}^2\mathcal{H}^{-1/2}(J^{\mathrm{loc}} - T_3\rho_3^{\mathrm{loc}})$$

The Dp-brane potential of the general form, depends on p

$$V = \frac{M_p^2}{4}\left\{\varphi(y) + \lambda\left[\overline{\Phi}_-(y) + \Phi_h(y)\right]\right\}$$

The noncancellation of DBI and CS terms

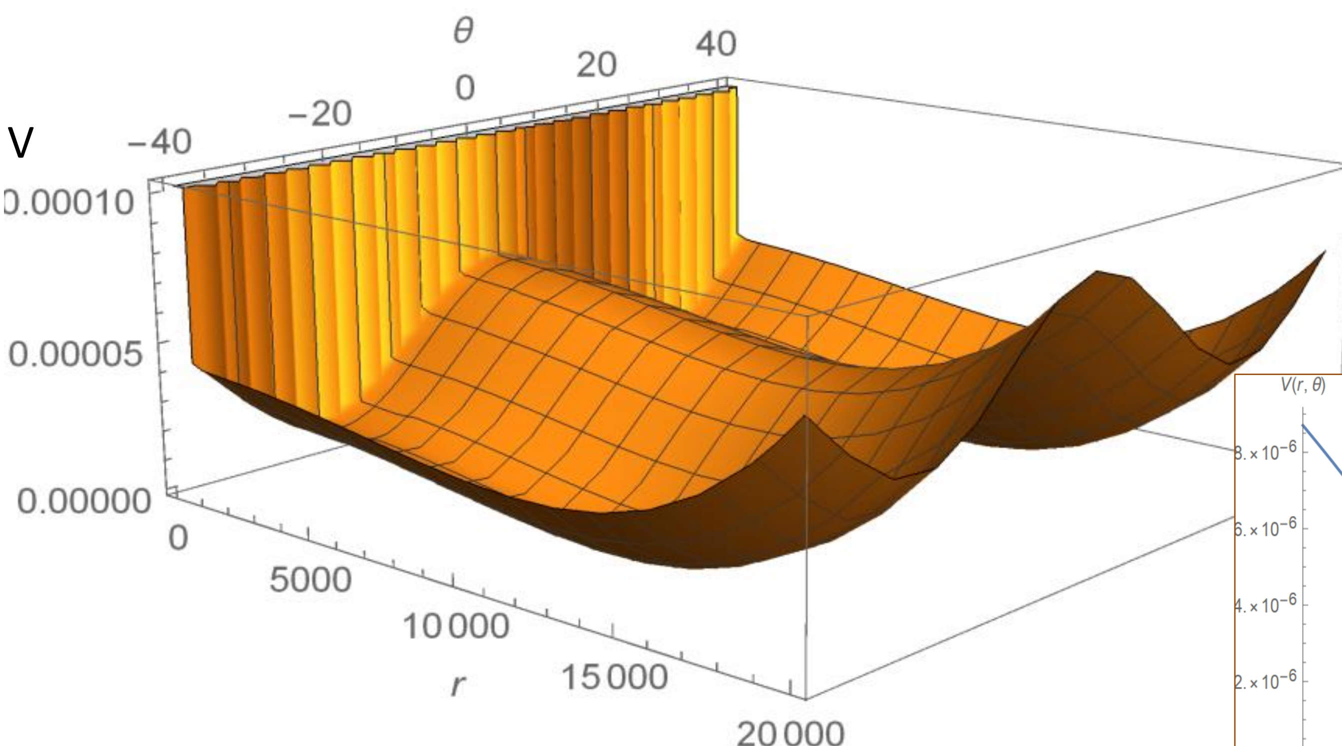
The inhomogeneous part of the solution to the Poisson equation

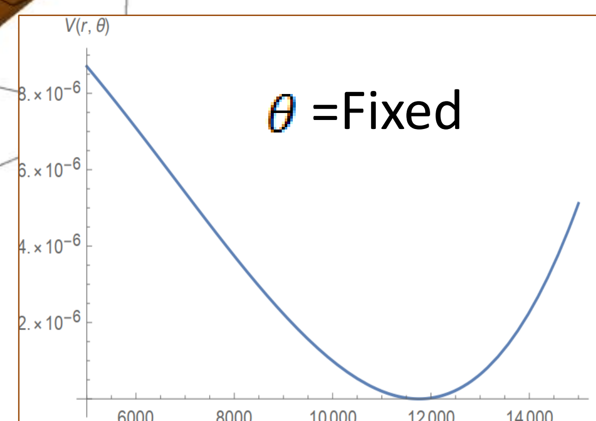
The nonconstant solution to the homogeneous Laplace equation on the RC.

Stress –free form of the potential

$$\mathbf{V}(\mathbf{r},\theta) = \frac{M_P^2}{4}\left(4\pi T_5 p \mathcal{H}^{-1}\left(\left[\frac{\mathcal{H}}{9}(r^2+3u^2)+(\pi l_s^2 q)^2\right]^{\frac{1}{2}} - \pi l_s^2 q\right) + \lambda\left(5.625\left(\frac{r^2}{u^2}-2\right)\frac{r^2}{3u^2}\right.\right.$$

$$\left.\left. -1.01 + 11.25\log[1+\frac{r^2}{9u^2}] + \frac{9a_0u^2}{r^2} - a_0\log[1+\frac{9u^2}{r^2}] + \frac{3}{2}b_1\left(2+\frac{27u^2}{r^2}\right)\cos\frac{\theta}{f}\right)\right)$$





EOMs

Taking number of e-folds as time variable Friedmann Equation takes the following form,

$$\frac{H^{'}(N)}{H(N)} = -\frac{1}{2}[\phi^{'}(N)^2]$$

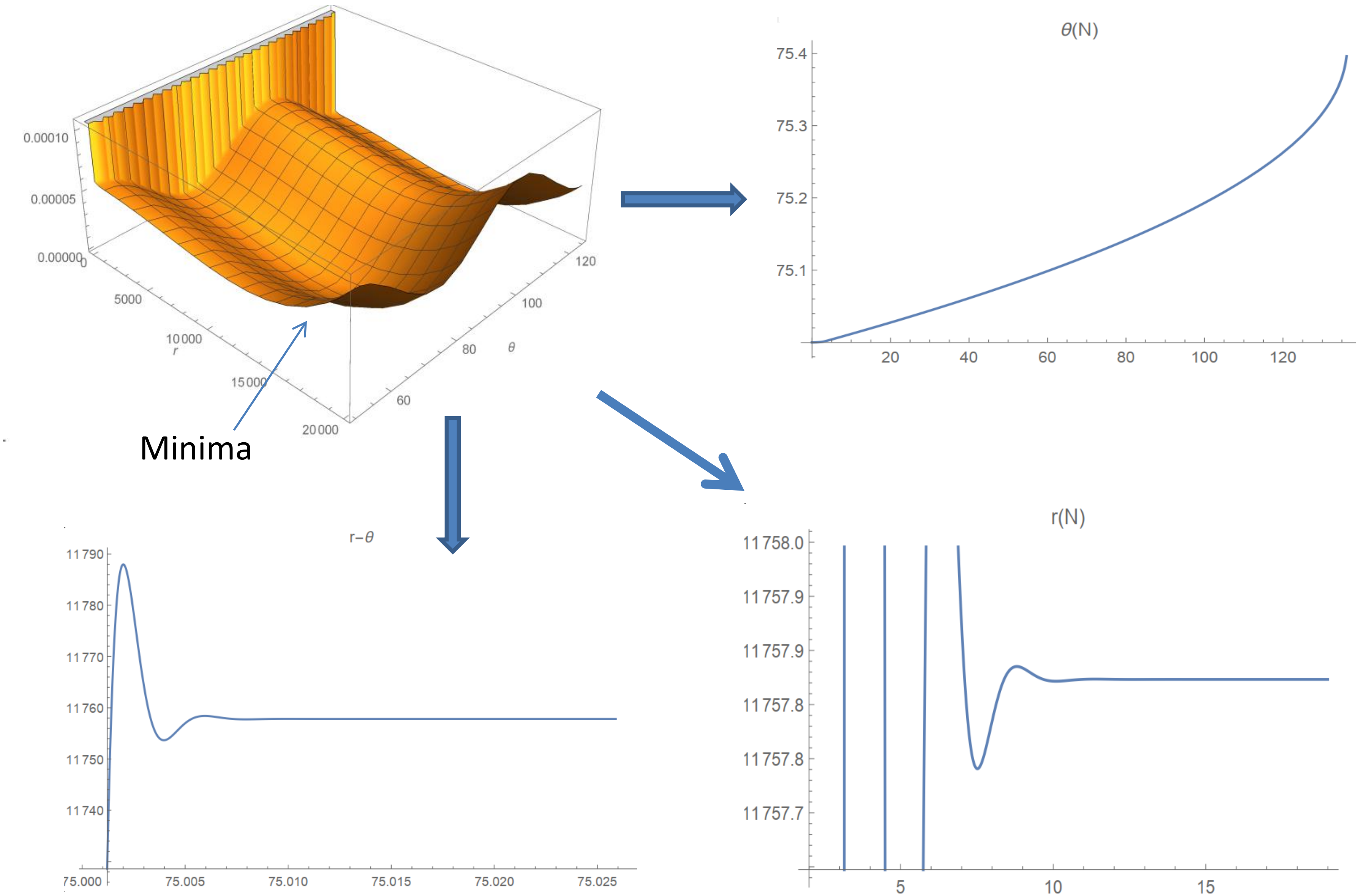
Where,

$$\phi^{'}(N)^2 = \frac{1}{2}\left[g_{lr}\frac{dx^l}{dN}\frac{dx^r}{dN}\right] \qquad (l, r) = 1, 2$$

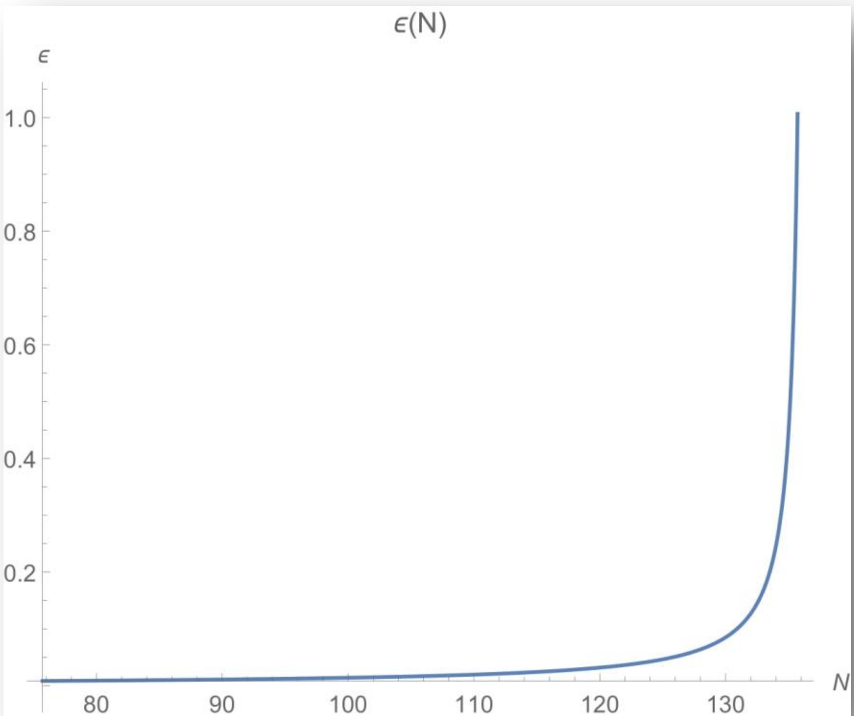
The scalar fields equations in the same domain takes the form,

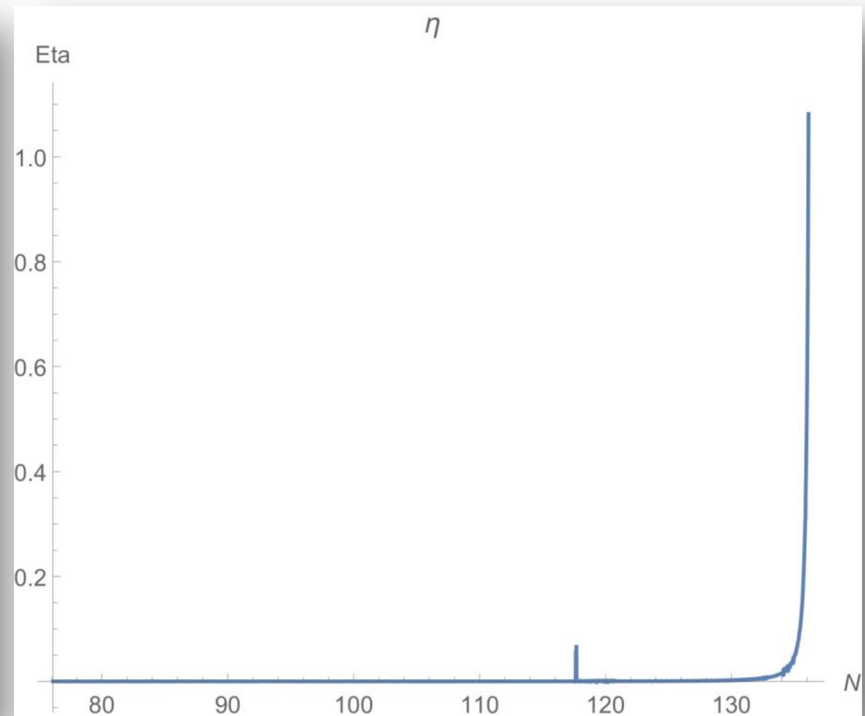
$$\Phi^{l''} + \Gamma^l_{rs}\Phi^{r'}\Phi^{s'} + 3\Phi^{l'} + \frac{H^{'}(N)\Phi^{l'}}{H(N)} + \frac{g^{lr}\partial_r V}{H(N)^2} = 0 \quad \text{Where } \Phi^l = (r, \theta)$$

Field behavior near the local minima



$$\epsilon, \eta \rightarrow 1$$





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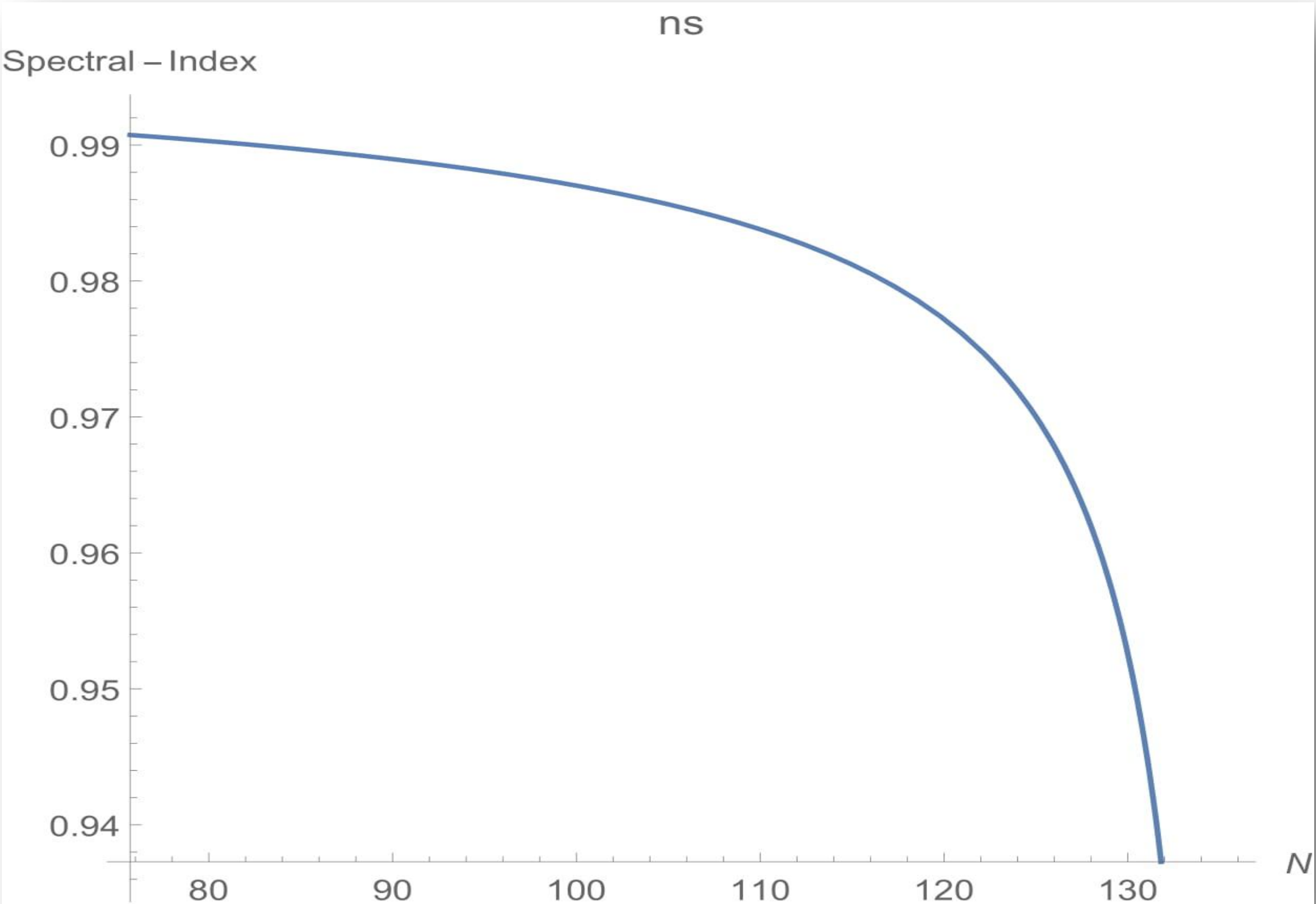
Observables



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Discussion

- To begin with we have taken the values of the various parameters of the potential as given by the authors for now.
- The inflation along angular direction is more significant than the radial one.
- We have to truncate the Warp factor and the potential at some suitable region in order to avoid large discrepancy in result- **Physical insight!**
- In order to compute the observables we considered the model similar to the single field scenario since the field associated to the radial coordinate has reached its minimum sooner than the angular direction.
- Trying to fit the model with observation.

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Outlook

- We are looking for better inflationary trajectory(IC) in order to avoid truncation of potential and warp factor.
- Trying to shape up the potential to match the observational constraint.
- The assumptions that we relaxed if that affects the backreaction on geometry and warp factor.
- Inflating using D3 branes also and compute the observables.
- Waiting for a hint of GW and\or ocurvature modes from new Planck data.

Thank you!