

(1)

ATTEMPTS AT INFLATION IN STRING THEORY

hep-th/0308055

K K L M (M) T
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LINDE
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PLAN:

- ① INTRODUCTION
- ② BRANE INFLATION IN
WARPED BACKGROUDS:
PROMISING ASPECTS
- ③ MODULI STABILISATION & MASS
FOR INFLATON: THE BAD NEWS
- ④ CONCLUSIONS

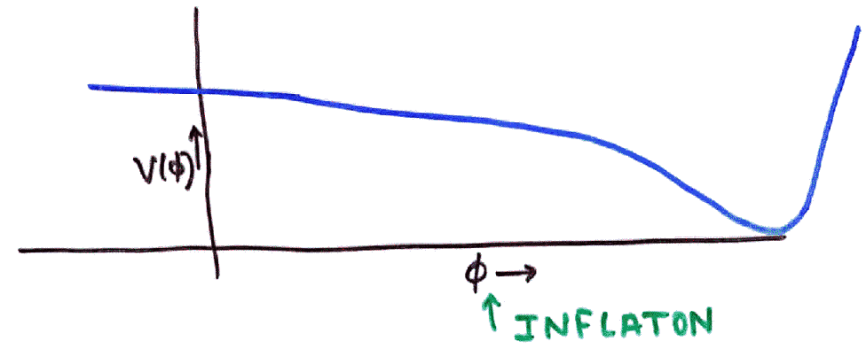
NOTATION: M_{10} : PLANCK SCALE 10-DIM.
 M_{PI} : PLANCK SCALE 4-DIM

SOME REFERENCES:

- DVALI & TYE : hep-th/9812483
- S. ALEXANDER : hep-th/0105032
- DVALI, SHAFI, SOLGANIK: hep-th/0105203
- BURGESS, MAJUMDAR, NOLTE, QUEVEDO, RAJESH, ZHANG : hep-th/0105204
- SHU & TYE : hep-th/0106274
- CHOUDHURY, GHOSHAL, JATKAR, PANDA : hep-th/0305104
- F. QUEVEDO : hep-th/0210292
- GIDDINGS, KACHRU, POLCHINSKI : hep-th/010509
- De WOLFE, GIDDINGS: hep-th/0208123
- KACHRU, KALLOSH, LINDE, TRIVEDI: hep-th/0301240
- BURGESS, KALLOSH, QUEVEDO : hep-th/0309187

INTRODUCTION:

INFLATION: EPOCH OF EXPONENTIAL EXPANSION.



- SLOWLY VARYING POTENTIAL REQUIREMENTS:

- e-foldings : $N_e \sim 60$
 - SLOW ROLL : $\epsilon = \left(\frac{V'}{V}\right)^2 M_{Pl}^2$
 - $\eta = \left(\frac{V''}{V}\right) M_{Pl}^2$ } SMALL
 - DENSITY PERTURBATIONS : δ_H SMALL
- RELATED TO MASS

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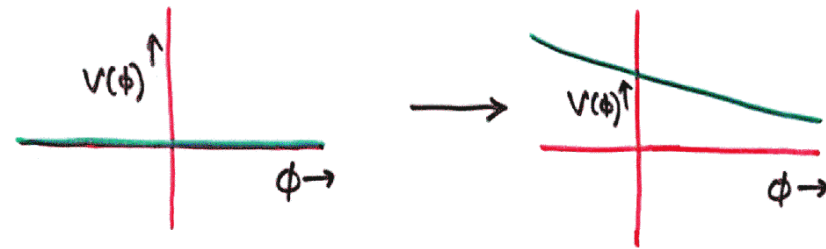
• ALSO NEED TO WORRY ABOUT:

- REHEATING
- INITIAL CONDITIONS

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INFLATION IN STRING THEORY:

- SO FAR DIFFICULT TO ACHIEVE
- MODULI PROMISING AT FIRST:



- BUT:
 - RESULTING POTENTIAL OFTEN TOO STEEP. E.g. DILATON:

$$V \sim e^{-1/g_s^2} \sim e^{-(e^{-2\phi})}$$

$$\eta \sim \frac{V''}{V} \sim \frac{1}{g_s^2} \gg 1 \text{ for } g_s \rightarrow 0$$
 - MANY MODULI. ANY STEEP DIRECTION WILL RUIN INFLATION.

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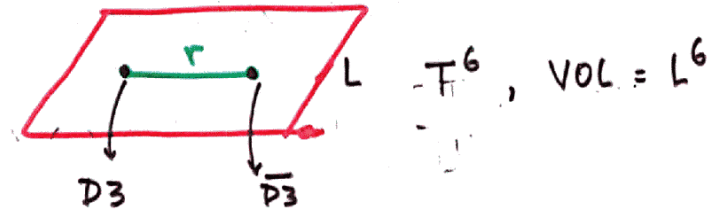
RECENTLY PROGRESS IN MODULI STABILISATIONS / SUSY BREAKING. SO IT IS TIMELY TO REVISIT THIS ISSUE.

GKP
KKLT

BRANE INFLATION:

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INFLATON: LOCATION (MODULUS) OF A BRANE.



$$V(r) = 2T_3 \left(1 - \frac{T_3}{(2\pi)^3 M_{10}^8 r^4} \right)$$

$$S = \int d^4x \left[\frac{1}{2} T_3 \dot{r}^2 - V(r) \right]$$

$$\eta = \frac{V''}{V} M_{Pl}^2 \sim \frac{T_3}{M_{10}^8 r^6} \frac{M_{Pl}^2}{T_3} \rightarrow \phi = \sqrt{T_3} r$$

$$M_{Pl}^2 = M_{10}^8 L^6$$

$$\eta = \frac{L^6}{r^6}$$

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SINCE $r \lesssim L$ $\eta \ll 1$ CANNOT BE POSSIBLE.

• ANOTHER PROBLEM:

IN 4-DIM EINSTEIN FRAME

$$V(r) = \frac{2T_3}{L^2} + \dots$$

• DEPENDS ON VOLUME

• VARIES RAPIDLY

 ϕ : CANONICALLY NORMALISED

$$L \sim e^{a\phi}$$

• STABILISATION OF "L" IMPORTANT.

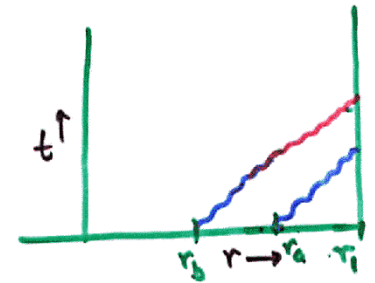
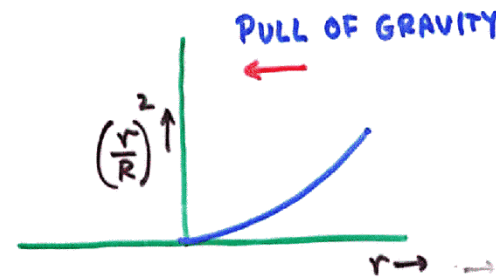
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WARPED BRANE INFLATION:

WARPED SPACETIMES

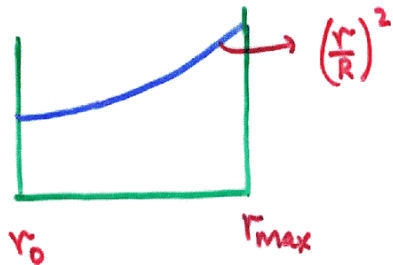
e.g: $AdS_5 \times S^5$ NOT IMPORTANT

$$ds^2 = \frac{r^2}{R^2} dx_{11}^2 + \frac{R^2}{r^2} dr^2 + R^2 d\Omega_5^2$$

R: SCALE OF AdS_5 .

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WE WILL CONSIDER A REGION OF AdS_5 THAT IS CUT OFF AT LARGE AND SMALL "r". (RS II)



BY RESCALING TAKE $\frac{r_{max}}{R} = 1$

$$[ds^2 = \frac{r^2}{R^2} dx_{11}^2 + \frac{R^2}{r^2} dr^2 + \dots]$$

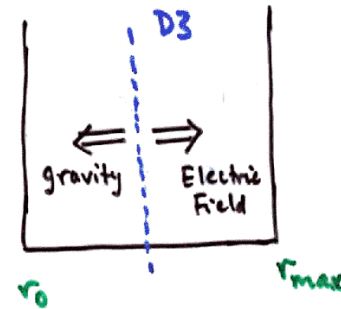
$$x_{11} \rightarrow \lambda x_{11}$$

$$r \rightarrow \frac{r}{\lambda}$$

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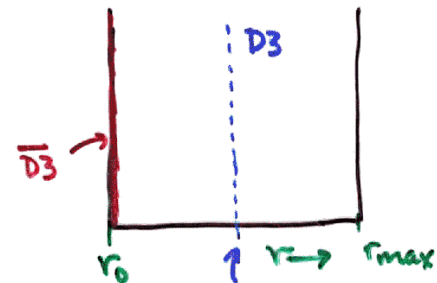
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IN STRING THEORY, THIS GEOMETRY IS SOURCED BY F_5 .



FORCES EXACTLY CANCEL FOR D3 BRANE

INTRODUCE $D3$ & $\overline{D3}$:



$D3$ EXPERIENCES FORCE ONLY DUE TO $\overline{D3}$.

- CAN D3 LOCATION BE THE INFLATON? (10)

$$V(r) = 2T_3 \left(\frac{r_0}{R}\right)^4 \left[1 - \frac{T_3 \left(\frac{r_0}{R}\right)^4}{(2\pi)^3 M_{10}^8 r^4} \right]$$

$\frac{r_0}{R}$: WARP FACTOR AT LOCATION OF $\overline{D3}$ BRANE.

SLOW ROLL?

$$\eta = \frac{V''}{V} M_{Pl}^2$$

$$M_{Pl}^2 \sim M_{10}^8 R^6$$

$$\eta = \left(\frac{r_0}{R}\right)^4 \frac{R^6}{r^6}$$

$\eta \ll 1$ CAN BE MET IF $\left(\frac{r_0}{R}\right) \ll 1$

$\epsilon \ll 1$ IS ALSO THEN SATISFIED.

$$\delta_H = C N_e^{5/6} \left[\frac{T_3}{M_{Pl}} \left(\frac{r_0}{R}\right)^4 \right]^{1/3} \quad (11)$$

$$\sim 1.9 \times 10^{-5}$$

• FOR $N_e \sim 60$

$$V^{1/4} = T_3^{1/4} \left(\frac{r_0}{R}\right) \cong 10^{14} \text{ GeV.}$$

$$\eta = -\frac{5}{6} \frac{1}{N_e} = -0.015$$

$$\epsilon \sim 10^{-11} \ll \eta.$$

$$\text{TILT } n = 1 - 6\epsilon + 2\eta \cong 0.97$$

• r : ratio of anisotropy due to gravity waves.
adiabatic density pert.

$$\cong 12.4 \epsilon \ll 1$$

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- THESE PARAMETERS ARE QUITE INDEPENDENT OF OTHER DETAILS OF MODEL.
- FOR $N_e \sim 60$ IN GOOD AGREEMENT WITH WMAP.



- COSMIC STRINGS
- D-STRINGS

$$\frac{T_D}{M_{Pl}^2} = \sqrt{\frac{2\pi}{g_s}} \left(\frac{V}{M_{Pl}^4} \right)^{\frac{1}{2}}$$

$$\text{FOR } \frac{g_s}{4\pi} \sim \text{dem} \sim \frac{1}{100}$$

$$\frac{T_D}{M_{Pl}^2} \sim 10 \times 10^{-8} \sim 10^{-7}$$

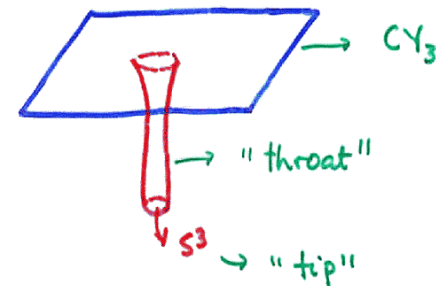
- OBSERVATIONALLY INTERESTING.

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GKP

STRING IMPLEMENTATION:

- COMPACT VERSION OF KLEBANOV - STRASSLER.
- IIB WITH FLUX ON CY_3 ORIENTIFOLD/ F-THEORY

 $F_{(3)}, H_{(3)}, F_{(5)}$ 

- CY_3 NEAR CONIFOLD SINGULARITY. SMALL S^3 .
- IN "THROAT" APPROXIMATE AdS_5 (+ log CORRECTIONS; $S^5 \rightarrow T^{(1,1)}$)
- ESSENTIALLY SAME STORY PLAYS OUT.

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• $\overline{D3}$ BRANE SITS AT THE TIP

• MAXIMUM RED SHIFT

$$\left(\frac{r_0}{R}\right)^4 \sim \exp\left(-\frac{8\pi}{g_s} \frac{k}{M}\right)$$

$$\left(\frac{r_0}{R}\right)^4$$

k, M: INTEGERS

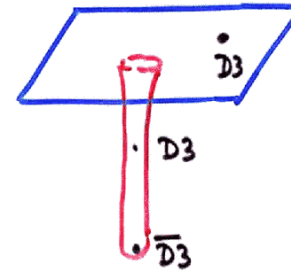
• CAN BE MADE SMALL "NATURALLY".

• DUAL GAUGE THEORY CONFINES IN IR. THE CONFINING SCALE, Λ .

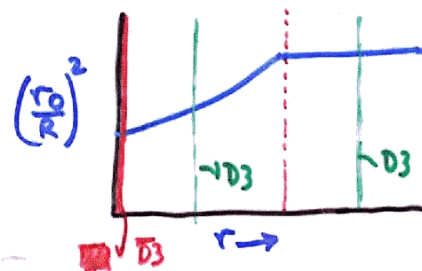
$$\frac{\Lambda}{M_5} \sim \left(\frac{r_0}{R}\right) \sim \exp\left(-\frac{2\pi}{g_s} \frac{k}{M}\right).$$

• "n" $\overline{D3}$'s, $n > 1$, RESCALES OVERALL POTENTIAL, SAME STORY.

• $D3$ BRANE CAN BE LOCATED IN "THROAT", OR AWAY FROM WARPED REGION.



• IN EITHER CASE, POTENTIAL WOULD BE GOVERNED BY SCALE, $T_3 \left(\frac{r_0}{R}\right)^4$.



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• OTHER MODULI ?

- IIB ~~on~~ ON CY_3 HAS
- COMPLEX STRUCTURE MODULI (SHAPE)
 - KAHLER MODULI (SIZE), ESP. VOLUME.
 - DILATON

THESE CAN ALL BE LIFTED:

- TURNING ON FLUXES: COMP. STRUC. & DILATON
- NON-PERTURBATIVE EFFECTS: VOLUME (GAUGINO CONDENSATION)

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VOLUME MODULUS:

SUPERPOTENTIAL STABILISATION:

$$W = W_0 + A e^{a\rho}$$

↑
DUE TO FLUX

↑
NON-PERTURBATIVE

- IN ABSENCE OF $D3$ -BRANES

$$\rho = \text{Vol} + ia$$

↓

VOLUME (e^{4u})

W FIXES VOLUME.

- IN PRESENCE OF $D3$ -BRANE

$$\rho = \text{Vol} + \frac{K(\Phi, \bar{\Phi})}{2} + ia$$

↑ KAHLER POT. OF BRANE MODULI.

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- SO RESULTING POTENTIAL FOR VOLUME STABILISATION NOW DEPENDS ON INFLATON TOO.
- RESULTING INFLATON MASS:

$$m^2 = \frac{1}{6} R_{\text{curv}}$$

• RUINS SLOW ROLL:

$$\eta = \frac{V''}{V} M_{\text{Pl}}^2 \sim \frac{R_{\text{curv}}}{V} M_{\text{Pl}}^2$$

$$R_{\text{curv}} \sim \frac{V}{M_{\text{Pl}}^2}$$

$$\eta \sim \mathcal{O}(1).$$

• BAD NEWS!

MIXING:

deWolfe & Giddings

$$P = \text{Vol} + \frac{K(\phi, \bar{\phi})}{2} + ia$$

WITH

$$K = -3 \ln(P + \bar{P} - K(\phi, \bar{\phi}))$$

- CORRECTLY REPRODUCES:

- KINETIC ENERGY TERMS INCLUDING NON-TRIVIAL MIXING BETWEEN a & $\bar{\phi}$
- NO-SCALE STRUCTURE

- UNDERLYING REASON: AXION CIRCLE NON-TRIVIAALLY FIBERED OVER $\bar{\phi}$ MODULI SPACE.

$$K(\phi, \bar{\phi}) \rightarrow K(\phi, \bar{\phi}) + f(\phi) + \bar{f}(\bar{\phi})$$

$$P \rightarrow P + f(\phi) \quad ; \quad \bar{P} \rightarrow \bar{P} + \bar{f}(\bar{\phi})$$

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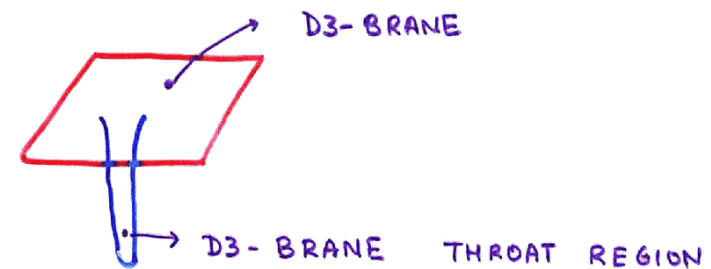
- ROUGHLY SPEAKING: KKL T
SUPERPOTENTIAL STABILISES, ρ ,
NOT VOLUME.
- THE ANTI-BRANE VACUUM ENERGY

$$V = \frac{2T_3}{(\text{Vol})^p} \exp\left(-\frac{8\pi k}{g_s M}\right)$$

$$V \sim \frac{2T_3}{\left[\rho - \frac{k(\phi, \bar{\phi})}{2}\right]^p} \exp\left(-\frac{8\pi k}{g_s M}\right)$$

$$\sim V_0 + \frac{V_0}{M_{\text{Pl}}^2} \phi \bar{\phi}$$
- SUGGESTS THAT OTHER SOURCES OF
VACUUM ENERGY, GOING LIKE, $\frac{1}{(\text{Vol})^\alpha}$,
WILL GENERICALLY HAVE SAME
PROBLEM.

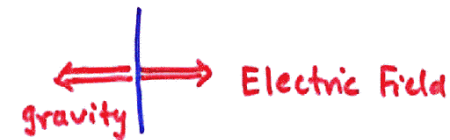
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- FOR D3-BRANE IN THROAT REGION

$$m^2 = \frac{1}{6} R_{\text{curv}}$$

FOLLOWS FROM AdS/CFT.

BRANE MODULI \leftrightarrow CONFORMALLY COUPLED
SCALARS.

- DO NOT EXACTLY CANCEL IF D3-
WORLD VOLUME CURVED.

$$ds^2 = \frac{r^2}{R^2} g_{\mu\nu} dx^\mu dx^\nu + \frac{R^2}{r^2} dr^2$$

$$\delta V = \frac{1}{6} R_{\text{curv}} \phi^2$$

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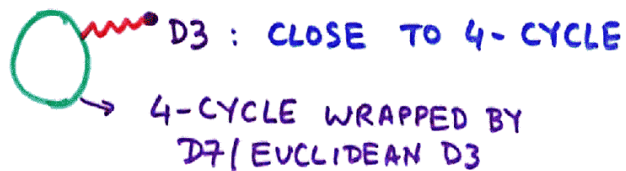
MORE COMMENTS ON MASS TERM:

. EFFECTIVE FIELD THEORY:

SYMMETRIES ALLOW:

$$\mathcal{L}_{\text{mass}} = c R_{\text{curv}} \phi^2$$

- . SO EXPECT THIS TERM IN GENERIC STRING COMPACTIFICATIONS.
- . THERE COULD BE WAYS AROUND:
 - a) NON-GENERIC SUPERPOTENTIAL



$$W_{\text{NP}}(p, \phi)$$

RESULTING MASS FOR ϕ COULD VANISH
(ALTHOUGH NOT IN AdS THROAT)

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- b) KÄHLER STABILISATION FOR VOLUME.
- c) OTHER BRANES : D5-D $\bar{5}$, D7-D $\bar{7}$
MIXING BETWEEN VOLUME &
INFLATON MAY BE AVOIDED.

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TWO ENCOURAGING FEATURES:

- e) RANGE OF VARIATION OF Φ
SMALL IN PLANCK UNITS

$$\frac{\Phi}{M_{\text{Pl}}} \sim \left(\frac{V_0}{M_{\text{Pl}}} \right)^{1/6} N e^{1/6}$$

AS A RESULT ONLY MASS TERM
NEEDS TO BE TUNED.

POTENTIAL $V = V_0 - \frac{a V_0^2}{\phi^4}$

CORRECTIONS $\delta V = V_0 \left(C_1 \frac{\phi^2}{M_{\text{Pl}}^2} + C_2 \frac{\phi^4}{M_{\text{Pl}}^4} + \dots \right)$

[CONTRAST: e.g. CHAOTIC INFLATION,
 $V = \lambda \phi^4, \phi \gg M_{\text{Pl}}$]

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- b) NATURAL MECHANISM FOR REHEATING:
 $D3 - \bar{D}3$ ANNIHILATION.

QUITE POSSIBLY, THIS DOES NOT
LEAD TO EXTRA COUPLINGS, DURING
SLOW-ROLL PERIOD, WHICH SPOILS
FLATNESS OF POTENTIAL.

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CONCLUSIONS :

- ① WARPED BRANE INFLATION IS PROMISING.
- ② DETAILS OF MODULI STABILISATION IMPORTANT.
- ③ GENERICALLY, SUPERPOTENTIAL STABILISATION OF VOLUME DOES NOT WORK.
- ④ NON-GENERICALLY IT COULD WORK. THE RESULTING INFLATIONARY PARAMETERS MIGHT DEPEND ON STABILISATION MECHANISM.

⑤ INFLATION COULD SIGNIFICANTLY RESTRICT THE ALLOWED GROUND STATES.

• THE TIME IS RIPE!