Title: Short Talks

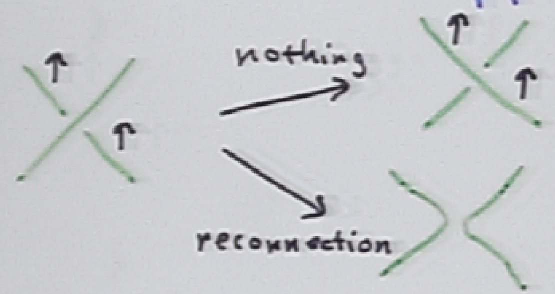
Date: Mar 29, 2005 05:00 AM

URL: http://pirsa.org/05030134

Abstract:

Collisions of Cosmic Superstrings

When strings collide, two things can happen:



$1-P$

P

- Gauge theory strings will always reconnect for $v < v_c \sim c$
- Super strings are probabilistic:

$$P_{FF} = \frac{\kappa^2}{\alpha' \pi V_\perp} \frac{\left(1-\cos\theta\sqrt{1-v^2}\right)^2}{8 \sin\theta \, v \sqrt{1-v^2}}$$

$$P_{DD} = \exp\left(\left[4 - g_s^{-1} \sinh \pi\varepsilon/2\right] e^{-\theta/\varepsilon}\right)$$

(MGJ, N. Jones, J. Polchinski 2004; Hanany & Hashimoto 2005)

But superstrings still have wavefunction in extra dimensions – what is the effect on P?

1) Only consider zero modes, so

$$P \sim V_{min}/V_{comp}$$

2) Calculate effective width of ψ in some potential, so

$$P \sim L_{min}/\langle(\Delta x)^2\rangle^{1/2}$$

Assuming $V(x) \sim m^2 x^2$,

$$\langle(\Delta x)^2\rangle \sim \ln(1 + 1/m^2)$$

Then these can be combined to study models with various geometries:
Example: KS throat has $\mathbb{R}^3 \times S^3$, so

$$P_{FF} \sim \frac{100\sqrt{g}}{M^{3/2} \ln^{3/2}(1+gM)}$$

where the $\mathbb{R}^3$ is a 3D SHO and the S^3 is averaged over with zero modes.

Short Talks

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Douglas Spolyar, *Chain Inflation*
Jan Pieter van der Schaar, *Tunneling away from the thermal dS vacuum*
Jason Kumar, *Landscape Cartography*
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Andrew Tolley, String Propagation on Bouncing Universes"
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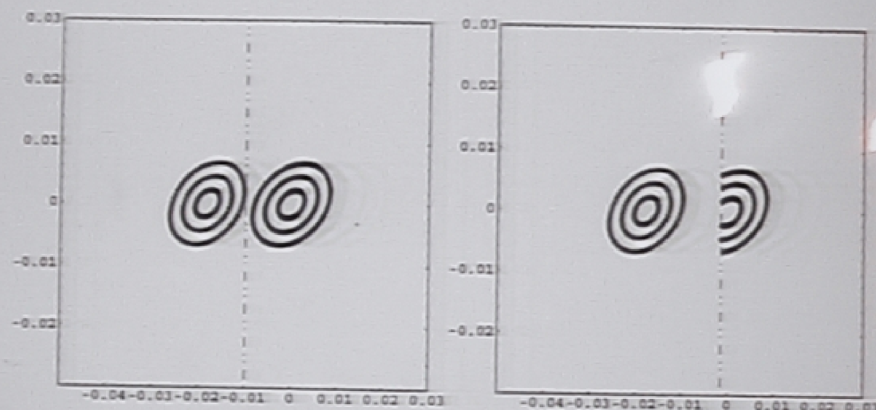
Within Brane Inflation,

Sarangi, Tye

Cosmic Strings are almost generic!

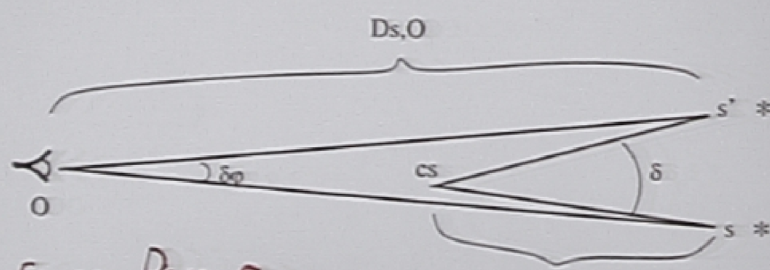
Current observational bound: $G\mu \lesssim 6 \times 10^{-7}$

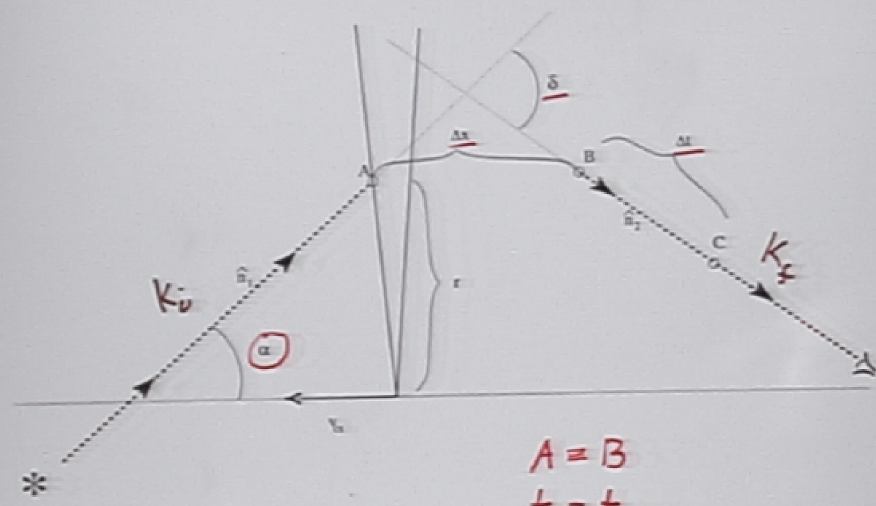


For a string at rest:

$$\delta = \delta_0 = 8\pi G\mu$$

Deflection angle of geodesic





$A = B$

$t_A = t_c$

$$k_f = \Lambda_{v_{cs}} \cdot R_{\delta_0} \cdot \Lambda_{-v_{cs}} \cdot k_i$$

moving strings lens more

$$\delta \approx \delta_0 \gamma_{cs} \left(1 + v_{cs} \cos(\alpha)\right)$$

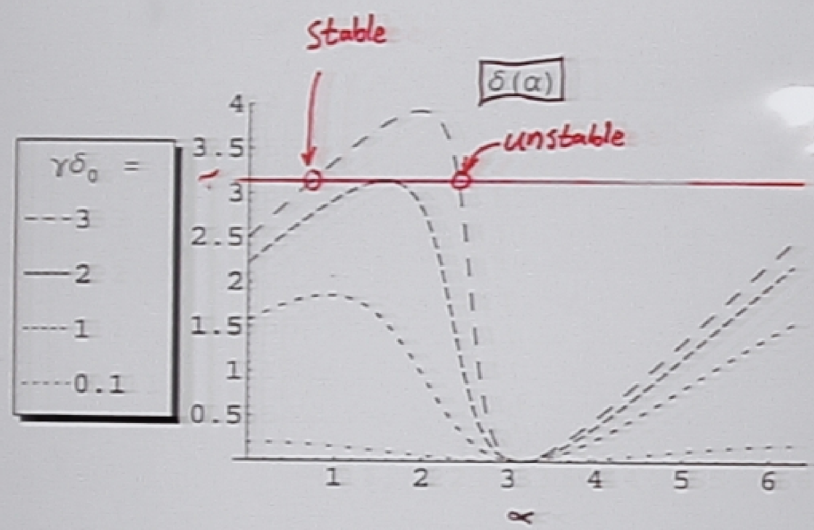
(corrects Vilenkin (1986))

$\delta_0 \gamma_{cs} \ll 1$

$$\frac{\omega_f}{\omega_i} \approx \frac{\delta^2}{2(1-\cos\delta)}$$

$$\gamma_{cs} = \frac{1}{\sqrt{1-v_{cs}^2}}$$

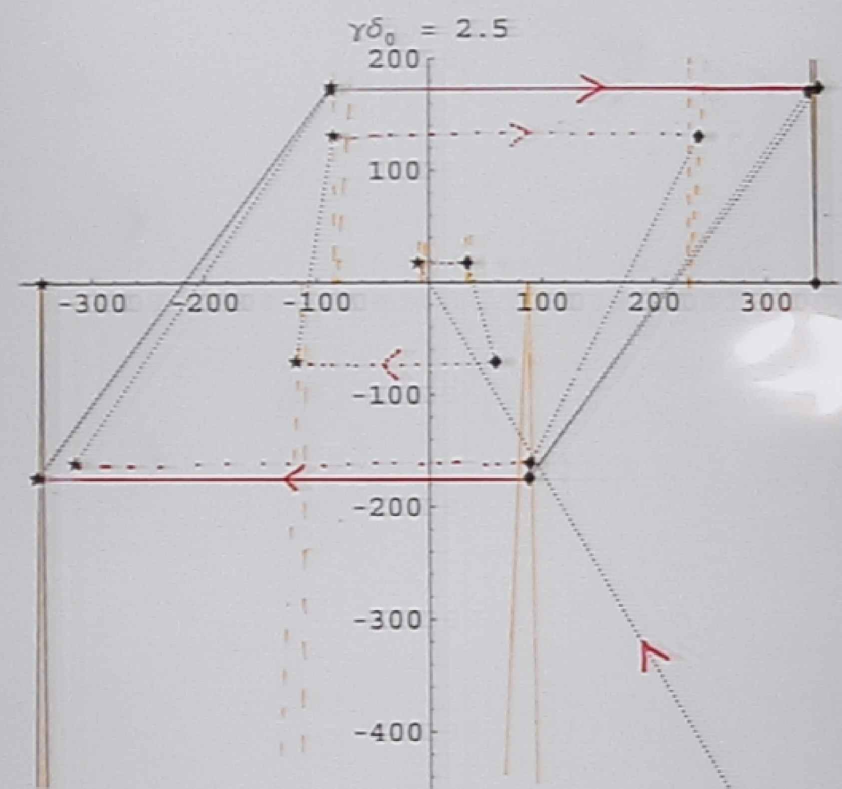
$\left.\begin{matrix}\Delta x \\ \Delta t\end{matrix}\right\}$ from relativity of simultaneity



Deflection of 180° means two cosmic strings could trap a particle

This is a CTC! Gott 1991

In agreement with Cotler 1992 ...



The CTC is an attractor.

notice: $\delta = \pi$ is a "fixed point" since the cosmic strings are moving opposite one another.

Pirsa: 05030134

Conclusion

- Moving Strings lens more
- Any dynamical field spoils the Gott Time Machine

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CHAIN INFLATION

K. Freese + Doug Spolyar
hep-ph/0412145

K. Freese, Jim Liu, Doug Spolyar
hep-ph/0502177

Inflation Requires
2 basic ingredients

1. Sufficient e-foldings of inflation
2. the universe must thermalize and reheat

Old inflation, with a single tunneling event, failed to do both.

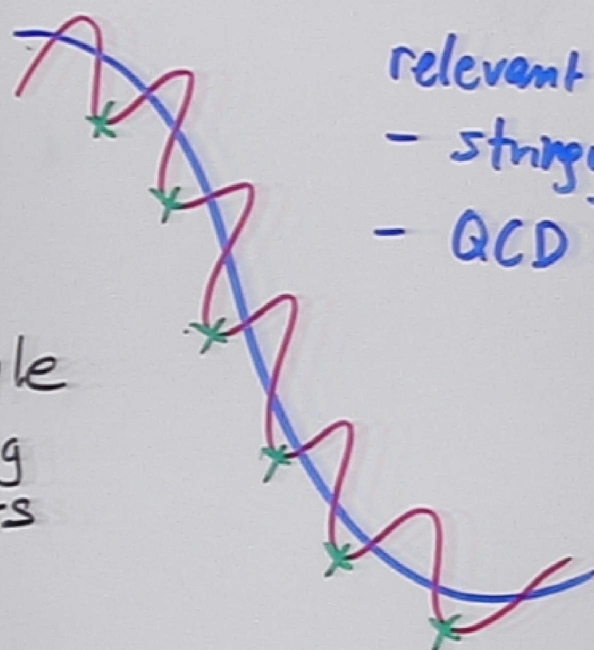
Here, multiple tunneling events

Each responsible for a fraction of an e-fold (adds to enough).

Graceful exit obtained:

Phase transition completes at each tunneling event.

Basic Scenario



Multiple tunneling events

relevant to:
- stringy landscape
- QCD (or other) axion

Graceful exit:

requires that the number of e-foldings per stage $\chi < 1/3$

Sufficient Inflation:

total number of e-folding $\chi_{tot} \geq 60$

Chain inflation-Basic Setup

- The universe transitions from an initially high vacuum energ
down towards zero.

  through a series of tunneling events

- The picture to consider: Tilted Cosine
- Solves Old inflation problem: Graceful Exit

  Sufficient Inflation-Many tunneling Events

Over Coming Short Comings
with Chain Inflation

- No Fine Tunning
- Large Range of Enegy Scales

  $10^{16} GeV$ to $10 MeV$

- Saves Old Inflation

  Graceful Exit- phase transition occurs very quickly

Tunneling away from the Thermal dS vacuum (in ≲ 5 min.)

Jan Pieter van der Schaar
ISCAP – Columbia U.

* Very preliminary, (lots of) work in progress with Brian Greene, Maulik Parikh

* Comments, (critical) remarks welcome

$\boxed{\text{T state}}$

* $\Gamma \sim e^{-\beta E}\left(1 + \frac{EH}{M_P} + ..\right)$ $\qquad$ $P_\phi \sim \left(\frac{H}{2\pi}\right)^2\left(1 + \mathcal{O}\left(\frac{H^2}{M_P^2}\right)\right)$

$\uparrow \qquad\qquad\qquad\qquad \updownarrow \qquad\qquad\qquad\qquad \uparrow$

$\Gamma \sim e^{-\beta E}$ $\qquad$ $P_\phi \sim \left(\frac{H}{2\pi}\right)^2$

$\boxed{\text{BD state}}$

Free falling $\longleftrightarrow$ comoving

* dS (Hawking-Gibbons) radiation as a tunneling effect

$\beta^{-1} = \frac{H}{2\pi}$

H. Parikh, F. Wilczek, hep-th/9907…
M. Parikh, hep-th/0204107

1 Min. * Tunneling approach: Backreaction due to be taken into account (Parikh [illegible])

$\Gamma \sim \exp(-2\,\mathrm{Im}\,[illegible]) = \exp(\Delta S)$; [illegible]

(Note: suggests restoration of unitarity)

$\Gamma = \exp[-[illegible]\,E\,(1 + [illegible])]$ M. Parikh, hep-th/[illegible]

2 Min. * Interpret this as a modification via thermal dS vacuum $|BD\rangle \rightarrow |T\rangle$

$b_k |F\rangle = 0$; $\langle BD | b_k^\dagger b_k | BD \rangle = \frac{1}{e^{[illegible]} - 1}$

$\langle T | b_k^\dagger b_k | T \rangle = \frac{1}{e^{[illegible]} - 1}$

3 Min. * Use linear Bogoliubov tf. to deduce how $|BD\rangle$ and $|T\rangle$ are related

$|\gamma_k| = \frac{|\beta_k|}{|\alpha_k|} = [illegible] \Rightarrow [illegible]$

$a_k^{(T)} = \alpha_k\, a_k^{(BD)} + \beta_k\, a_k^{\dagger (BD)}$

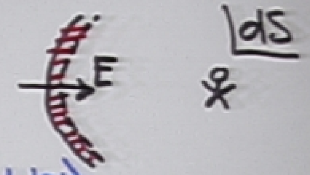
4 Min. * Seems phenomenologically irrelevant: $O(\frac{H}{M_p})$

Theoretically interesting

Backreaction effect

Any Comments?

1 Min. * Tunneling approach :
backreaction has to be taken into account (S-wave WKB)



$$\Gamma \sim \exp\left(-2\,\mathrm{Im}\,\frac{I}{\hbar}\right) = \exp(\Delta S)\ ; \quad S = \frac{A_h}{4G}$$

(Note: suggests restoration of unitarity)

$$\Gamma \approx \exp\left[-\frac{2\pi}{H}E\left(1+\frac{EH}{M_p^2}\right)\right]$$

M. Parikh, hep-th/0405?

2 Min. * Interpret this as a modification to the thermal dS vacuum $|BD\rangle \longrightarrow |T\rangle$

$$b_k|F\rangle = 0\ ; \quad \langle BD|\,b_k^{+} b_k\,|BD\rangle = \frac{1}{e^{\beta E}-1}$$

$$\langle T|\,b_k^{+} b_k\,|T\rangle = \frac{1}{e^{C(E)}-1}$$

3 Min. * Use linear Bogolubov t.f. to deduce how $|BD\rangle$ and $|T\rangle$ are related

$$|\gamma_k| \equiv \frac{|\beta_k|}{|\alpha_k|} = \frac{e^{C(k)} - e^{\frac{1}{2}\beta|k|}}{e^{C(k)+\frac{1}{2}\beta|k|}-1} \Rightarrow P \approx P_0\left(1+\mathcal{O}\left(\frac{H^2}{M_p^2}\right)\right)$$

$$a_k^{(T)} = \alpha_k\, a_k^{(BD)} + \beta_k\, a_k^{+(BD)}$$

4 Min. * Seems phenomenologically irrelevant : $\mathcal{O}\left(\frac{H^2}{M_p^2}\right)$
Theoretically interesting
Backreaction effect

Any Comments ?

Landscape Cartography- JK and James Wells

Uses of the landscape:

- which vacuum? → input for model-builders
- why? → vacuum selection principle

model-building → need selection criteria

→ but not too generic

↪ selects too many "wrong" models

⇒ want real-world features which are tractable for model-builder, but non-generic on landscape

↓

need distributions of observable parameters on landscape

initial step → gauge grp. rank (D3-branes)

$\langle N_{D3}\rangle = \frac{L_*}{2n+3}$ where $n = \#$ cpx. struc. mod.

(L_* =D3-charge of background)

$$\boxed{\textbf{rank probability density} = \rho = \frac{1}{\langle N_{D3}\rangle} e^{-\frac{R}{\langle N_{D3}\rangle}}}$$

- in small c.c. limit, replace $\langle N_{D3}\rangle = \frac{L_*}{2n+2}$
- small c.c. and gauge grp. rank are *slightly correlated*

Vacuum selection principle → effective M-theory?

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Fast Presented Fast Quenching

March 28, 2005

Neil Barnaby, Aaron Berndsen, James M. Cline, and H. S. hep-th/0412095

The First Transparency

- Real tachyon action:

$$S = \int \sqrt{-g} V(T) \sqrt{1 + \partial_\mu T \partial^\mu T} \ , \ \ V(T) = e^{-T^2/2M_S^2}$$

- Equation of motion in Minkowski space-time:

$$\partial_\mu \partial^\mu T - \frac{\partial_\alpha \partial_\beta T \partial^\alpha T \partial^\beta T}{1 + \partial_\sigma T \partial^\sigma T} - \frac{1}{V}\frac{\partial V}{\partial T} = 0$$

- Homogeneous field in FRW space-time:

$$\ddot{T} + 3\frac{\dot{a}}{a}\dot{T}\left(1 - \dot{T}^2\right) + \frac{V'(T)}{V(T)}\left(1 - \dot{T}^2\right) = 0, \quad \text{Solution:} \quad \ddot{T} = 0 \ , \ \ \dot{T} = \pm 1$$

With the ansatz $T(t,x) = (x - x_0)\, u(t)$ the equation for $u(t)$ at $x = x_0$ is:

$$\ddot{u} = \frac{2}{b^2}u + \frac{u\dot{u}^2}{1+u^2} - 3H\dot{u}, \quad \text{Solution:} \quad u(t) \sim \frac{k}{t - t_0}$$

If we have a complex tachyon field with action

$$S = \int d^{p+1}x \sqrt{-g} V(T) \left(1 + \partial_\mu T \partial^\mu T\right)$$

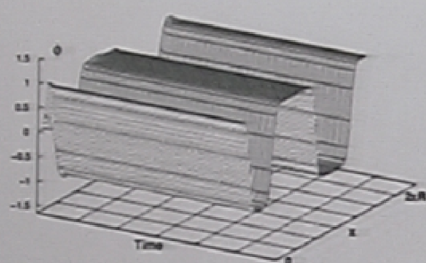
the ansatz

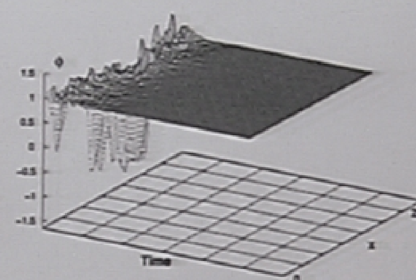
$$\begin{aligned} T_1(t,x,y) &= (x - x_0)\, u(t) \\ T_2(t,x,y) &= (y - y_0)\, u(t) \end{aligned}$$

gives the equation $\ddot{u} - \frac{2}{b^2}u = 0$. The slope is exponentially increasing, but finite at all times. If we naively extend the real tachyon action to the complex case the slope diverges again in finite time.

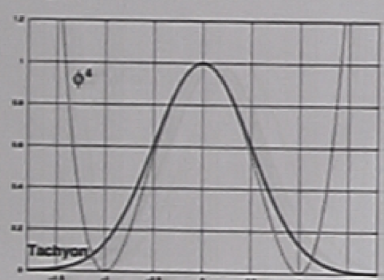
The Second Transparency

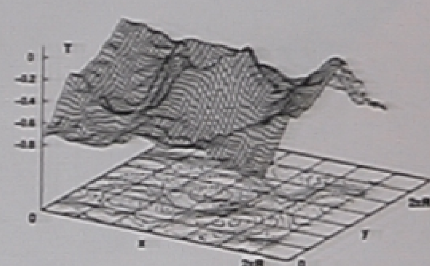
In the case of ϕ^4 theory the density of defects is determined by how fast the energy is being dissipated. A small damping allows for efficient homogeneization and a small density of defects.





In the case of the tachyon the runaway potential produces a very fast quenching effectively “freezing” the fluctuations. Once the gradients become large, the evolution becomes independent of the shape of the potential.





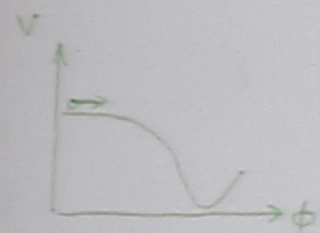
Multi-Throat Brane Inflation

Xingang Chen
University of Florida

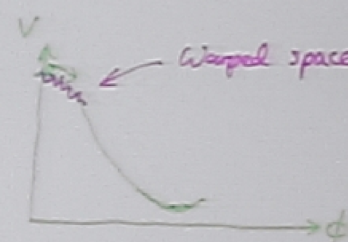
hep-th/0501184 , 0408084 , 0406198

① A new class of Inflation Models — Speed-Limit Inflation

② A realization in multi-throat string compactification.



$\eta \ll 1$: slow-roll



$\eta \gtrsim 1$: Speed-limit

- Using Warped space :

$$ds^2 = \frac{r^2}{R^2}\left(-dt^2 + a^2(t)\, d\vec{x}^2\right) + \frac{R^2}{r^2} dr^2 \quad , \quad r \equiv \phi / \sqrt{T_3}$$

Speed-Limit : $\dot{r} \le \frac{r^2}{R^2}$ E.g. KS-GKP model : $\left.\frac{r}{R}\right|_{min} \sim e^{-\frac{2\pi K}{3 g_s M}}$

Silverstein, Tong hep-th/0310221 ;
Alishahiha, Silverstein, Tong, 0404084
X.C. 0408084, 0501184

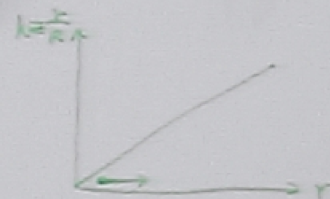
Field theory of Speed-Limit Inflation

X.C. 0408084, 0501184

- Action

$$S = \frac{M_{pl}^2}{2}\int d^4x\sqrt{-g}\,R - T_3\int d^4x\sqrt{-g}\left[h^4\sqrt{1+h^{-4}g^{\mu\nu}\partial_\mu r\,\partial_\nu r} - h^4 + V(r)\right]$$

$\left(h = \frac{r}{R}\right)$



Potential : $V(r) \approx V - \frac{1}{2}\beta H^2 r^2$

with $\beta \gtrsim 1 \Rightarrow \eta \gtrsim 1$. no slow-roll inflation.

- Zero-mode solution

$$r = -\frac{R^2}{t} + \frac{9R^2}{2\beta^2 H^2}\frac{1}{t^3} + \cdots \qquad (\text{choosing } t \text{ run from } -\infty)$$

for $t \ll -H^{-1}$

- Back-reactions

① D3-brane (Inflaton) backreaction : $t \gg -3N\beta^{-1}H^{-1}$

Multiple M D3-branes : $t \gg -3k\beta^{-1}H^{-1}$

② closed string creation by dS space : $t \gtrsim -\sqrt{N}\,H^{-1}$

$\left[\begin{array}{l} N = Mk : \\ \text{throat's} \\ \text{D3-charge} \\ k \sim M \sim \sqrt{N} \end{array}\right]$

- Inflationary Window ;

$$-3\sqrt{N}\,\beta^{-1}H^{-1} \ll t \ll -H^{-1}$$

total inflationary e-folds :

$$N_{tot} = H\Delta t \sim \sqrt{N}/\beta$$

E.g. $N = Mk$, $M \sim k \sim 10^2$, $\beta \sim 1$

Field theory of Speed-Limit Inflation

X.C. 0408084, 0501184

- Action

$$S = \frac{M_{pl}^2}{2}\int d^4x\sqrt{-g}\,R - T_3\int d^4x\sqrt{-g}\left[h^4\sqrt{1+h^{-4}g^{\mu\nu}\partial_\mu r\,\partial_\nu r} - h^4 + V(r)\right]$$

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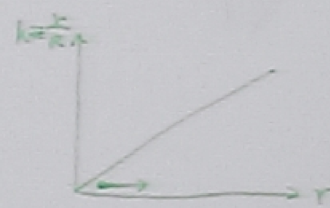

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Multiple M D3-branes: $t \gg -3k\beta^{-1}H^{-1}$

② closed string creation by dS space: $t \gtrsim -\sqrt{N}\,H^{-1}$

[$N = Mk$: throat's D3-charge, $k \sim M \sim \sqrt{N}$]

- Inflationary Window,

$$-3\sqrt{N}\,\beta^{-1}H^{-1} \ll t \ll -H^{-1}$$

total inflationary e-folds:

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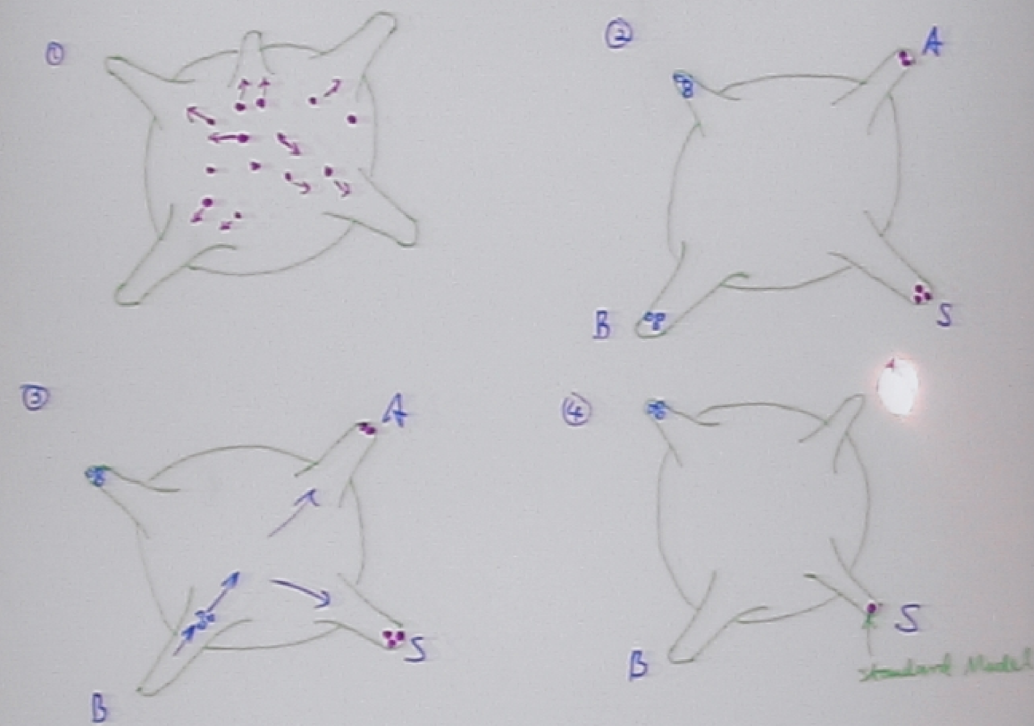
E.g. $N = Mk$, $M \sim k \sim 10^2$, $\beta \sim 1$

Multi-Throat Brane Inflation Scenario

X.C. 0408084, 0501184

• $\overline{D3}$ ∘ $D3$



- large inflationary e-folds;
- Scale invariant density perturbations with interesting features;
- Incorporating Randall-Sundrum model;
- Direct reheating;
- Possible creation of cosmic strings;
- A possible stringy mechanism for IR suppression on CMB.
- Open Questions ......

No Fine-tuning in Inflation?

S.E. Shandera
with S.-H. H. Tye
Cornell University

based in part on
Firouzjahi & Tye
hep-th/0501099

Better observational data

+

Development of detailed string models

Model

- → D3/$\overline{D3}$, D3/D7, multi-throat
- → SM
- → stabilize all moduli
- → superpotential, kahler potential, corrections
- → slow-roll?

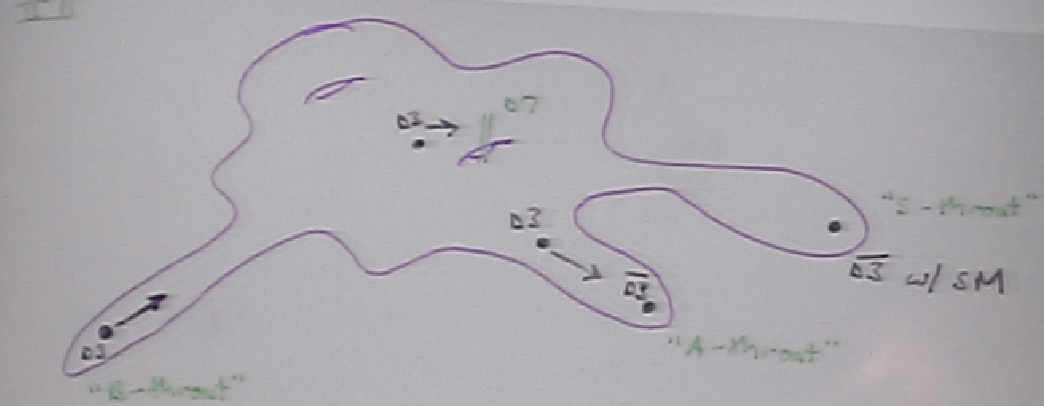
Observation

- → cosmic string tension
- → n_s, r, $\frac{dn}{d\ln k}$, ...

* Kachru, Kallosh, Linde, Maldacena, McAllister, Trivedi
* Alishahiha, Silverstein, Tong; Chen
* Denef, Douglas, Florea, Grassi, Kachru
* Berg, Haack, Kors; McAllister

* Firouzjahi, Tye

→ What range of parameters in a general model agrees with current data?



① Slow-roll (KKLMMT)

$$\eta_{SR} = M_P^2 \frac{V''}{V} \ll 1$$

↳ $V_{D\bar{D}}$ flat from warping

↳ $m^2 \sim H^2$ found after stabilizing moduli

↳ $\sim 1/100$ fine-tuning

* H. Firouzjahi + H. Tye using WMAP observables $\Rightarrow \sim 1/6$

② Fast-roll (Silverstein-Tong) (Chen-multi-throat)

↳ DBI action, $V = m^2\phi^2$

↳ steep potential, fast-rolling brane, still match observation

* more tensor modes
* high non-Gaussianity

③ General case

$$V = m^2\phi^2 + 2T_s h_A^4 \left[1 - \frac{1}{N_A} \frac{\phi_A^4}{(\phi-\phi_A)^4} \gamma \right] + \dots$$

(hard

$\rightarrow \quad N_e = \frac{1}{M_P^2} \int \frac{V}{V'} \, d\phi$

* easier to get $N_e \sim 60$ when $V_{e\bar{e}}$ included

$\rightarrow \quad n_s - 1 \sim \underbrace{-4\epsilon_H + 2\eta_H - 2\kappa_H}_{\rightarrow 0 \text{ in fast-roll limit}} + 2(1+c)\epsilon_H^2 + \dots$

$\kappa = \frac{2M_P^2 g_1}{\gamma} \left(\frac{H'}{H} \frac{\gamma'}{\gamma} \right)$

$\rightarrow \quad r \sim \frac{16\epsilon_H}{\gamma}$, $f_{NL} \propto \gamma^2$, $\gamma = \sqrt{1 + 4g^2 M_P^4 f(\phi) [V'(\phi)]^2}$

$\therefore H \sim$ constant $\Rightarrow \gamma \sim 1$

(< 0.36)

[slow-roll $r \sim 16\epsilon_H$]

* Allowing "general-roll" ⇒ no fine-tuning needed for parameters in $V(\phi)$ *

* Procedure for finding constraints directly from observation *

* Not limited to slow roll *

→ From $V(\phi)$, DBI action, Friedmann equations, find $H(\phi)$, $\gamma(\phi)$

→ Use "Hubble slow roll" expansion parameters

↳ really no slow-roll assumption (Liddle, Parsons, Barrow)

$$\epsilon_{HSR} \equiv \frac{2M_p^2 g_s}{\gamma}\left[\frac{H'(\phi)}{H(\phi)}\right]^2$$

$$\eta_{HSR} = \frac{2M_p^2 g_s}{\gamma}\left[\frac{H''(\phi)}{H(\phi)}\right]$$

$$\vdots$$

note

$$\frac{\ddot{a}}{a} = H^2[1-\epsilon_{HSR}]$$

$\therefore$ $\epsilon < 1 \Rightarrow$ inflation

$\epsilon = 1 \Rightarrow$ inflation ends

$$\epsilon_{SR} = \epsilon_{HSR}\left[\frac{6-2\eta_{HSR}}{3-2\epsilon_{HSR}}\right]^2 \quad \text{etc.}$$

($\epsilon_{HSR} \ll 1 \rightarrow$ slow roll)

* Expand all observables in HSR parameters (+ γ factors) and fit to model

$\rightarrow \quad N_e = \frac{1}{M_P^2} \int \frac{V}{V'} \, d\phi$

*easier to get $N_e \sim 60$ when $V_{D\bar{D}}$ included

$\rightarrow \quad n_s - 1 \sim \underbrace{-4\epsilon_H + 2\eta_H - 2\kappa_H}_{\rightarrow 0 \text{ in fast-roll limit}} + 2(1+c)\epsilon_H^2 + \ldots$

$$\kappa = \frac{2M_P^2 g_1}{\gamma} \left(\frac{H'}{H} \frac{\gamma'}{\gamma} \right)$$

$\rightarrow \quad r \sim \frac{16\epsilon_H}{\gamma}, \quad f_{NL} \propto \gamma^2, \quad \gamma = \sqrt{1 + 4g_1^2 M_P^4 f(\phi) \left[H'(\phi) \right]^2}$

$\therefore H \sim$ constant $\Rightarrow \gamma \sim 1$

(< 0.36)

[slow-roll $r \sim 16\epsilon_H$]

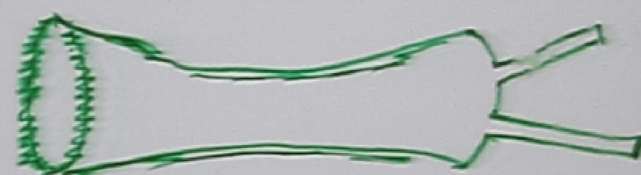
* Allowing "general-roll" ⇒ no fine-tuning needed for parameters in $V(\phi)$ *

* Procedure for finding constraints directly from observation *

* Not limited to slow roll *

Brane Reheating from $D\bar{D}$ Annihilation

Louis Leblond
Cornell University.



In collaboration with Nicholas Jones

(Work in progress)

Exit of $D\bar{D}$ Brane inflation

- $D\bar{D}$ annihilation $\longrightarrow$ Tachyon Condensation

  ↳ Vacuum Energy $\longrightarrow$?

- Low energy effective action do not hold

  ↳ stringy physics comes in that could be tested (e.g. Cosmic Strings)

- Experimental Constraints on reheating are very weak

  ↳ bath of standard model like radiation $T \gtrsim M_{EW}$

- Question: what is the branching fraction of $D\bar{D}$ going to open string vs closed string ?

To leading order

- $D\bar{D}$ goes to closed strings
  - → L/R identical
  - → Non-relativistic
  - → very massive
  - → ...

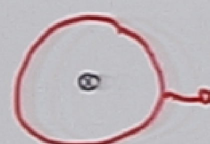
(Liu, Lambert & Maldacena 2003)

- time dependent source → coherent state

$$|0\rangle_{out} = e^{\alpha a^\dagger}|0\rangle$$

$a^\dagger$: creation op. for a phys. closed string.

$$\sqrt{2E}\,\alpha = \mathcal{A}$$

$\mathcal{A} =$  → $D\bar{D}$ bdry $\qquad g_s^0$

$$|B\rangle \sim \int dE \, \frac{e^{i\varphi(E)}}{\sinh(\pi E)} |0\rangle + \cdots$$

$$\bar{N} = \sum_s \frac{1}{2E_s} |\mathcal{A}_s|^2$$

* $\mathcal{A}$ is the same for each closed string at level n

$E \gg$

$$\bar{N} = \sum_n \underbrace{\left(\begin{matrix}\text{exponential}\\ \text{suppression}\end{matrix}\right)}_{\text{from } \mathcal{A}} \otimes \underbrace{\left(\begin{matrix}\text{exponential}\\ \text{growth}\end{matrix}\right)}_{\text{from } D(n)} \times \text{power law}$$

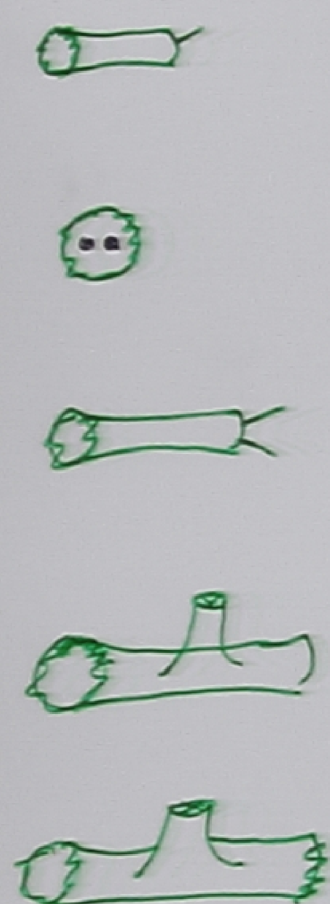
cancels

NLO

* Suppose the existence of open string d.o.f.
$DD\bar{D}$

$g_s^{1/2}$

g_s

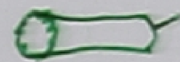


(Chen, Okuda & Sugimoto)

NLO

* Suppose the existence of open string dof $D\bar{D}$

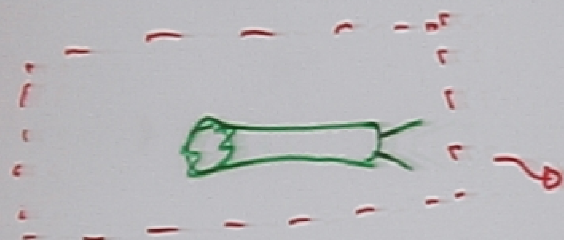
$g_s^{1/2}$



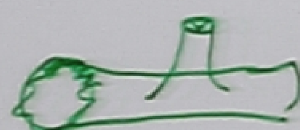
* Assumptions

$\lambda \simeq$ same for all open string at level n

g_s



exponential suppression cancel exponential growth from $D(n)$



emmitting a L/R identical closed string or 2 open have similar properties

(chen, Okuda & Sugimoto)

* Non trivial factor of $\frac{1}{2}$; $E \to \infty$

factor of 2 b/c 2 open

* pair production

$|0\rangle_{out}$ = squeezed state

Concluding Remarks

- Need the full bndy state (not just zero mode)

1) ZZ (Gutperle & Strominger)

$$|B\rangle_{ZZ} = \int dw\, e^{-iw\log\tilde{\lambda}} \frac{-i\pi}{\sinh \pi w} |w\rangle\rangle$$

This is the correct bndy state to use.

2) Sen's

$$|B\rangle_{x^0} = \sum_j \sum_{m\geq 0}^{j} \binom{j+m}{2m} (i\tilde{\lambda})^{2m} |j,m,m\rangle\rangle$$

lead to divergent terms in 1-loop $\sim e^t$

(Okuda, Sugimoto, Chen, Sen, ...)

way simpler & well defined

- $\mathcal{A} = \langle B| q^{L_0+\tilde{L}_0} V_0 V_0 |D\rangle \sim e^{-\alpha E} (g(E))$

depends on final

Short Talks

Mark Jackson, *Collisions of Cosmic F- and D-strings*
Ben Shlaer, *Cosmic string lensing and closed time-like curves*
Douglas Spolyar, *Chain Inflation*
Jan Pieter van der Schaar, *Tunneling away from the thermal dS vacuum*
Jason Kumar, *Landscape Cartography*
Horace Stoica, *Fast Presented Fast Quenching*
Xin-gang Chen, *Multi-throat brane inflation*
Sarah Shandera, *No fine-tuning in brane inflation?*
Louis Leblond, *Brane Reheating from Brane Anti-Brane Annihilation*
Marcus Berg, *Orientifold Prepotentials*
Andrew Tolley, String Propagation on Bouncing Universes"
Joshua Friess, *String Creation in Time-Dependent Backgrounds*
Steve Morris, *Stabilizing G_2 Moduli*

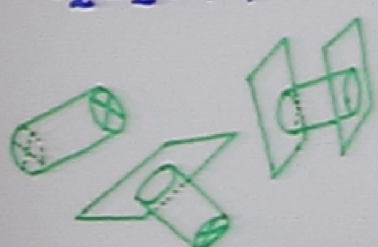
ORIENTIFOLD PREPOTENTIALS

Marcus Berg
(KITP)
M. Haack
B. Körs

$$E_2(A,U) = \sum \frac{(U-\bar{U})^2}{|n+mU|^4} \exp\left(2\pi i \, \frac{A(n+m\bar{U}) - \bar{A}(n+mU)}{U-\bar{U}}\right)$$

- $\mathrm{Re}\left(Li_4(e^{i\theta})\right) = \sum_{n=1}^{\infty} \frac{\cos n\theta}{n^4} = \frac{\pi^4}{90} - \frac{1}{48}\theta^2(2\pi-\theta)^2$
- $y^{-s} = \frac{1}{\Gamma(s)} \int_0^{\infty} dx \, x^{s-1} e^{-yx}$
- $\int_0^{\infty} dx \, x^{\nu-1} e^{-\beta/x - \gamma x} = 2\left(\frac{\beta}{\gamma}\right)^{\nu/2} K_\nu(2\sqrt{\beta\gamma})$

$$U_2 \mathcal{E}_2(A,U) = 2f + 2\bar{f} - (U-\bar{U})(\partial_U f - \partial_{\bar{U}} \bar{f}) - (A-\bar{A})(\partial_A f - \partial_{\bar{A}} \bar{f})$$



$$h(A,U) = \frac{2\pi^4}{8i}\left(\frac{1}{90}U^3 - \frac{1}{3}UA^2 + \frac{2}{3}A^3\right) + \frac{\pi}{4}Li_3(e^{2\pi i A})$$
$$+ \frac{\pi}{4}\sum_{m>0}\left[Li_3(e^{2\pi i(mU-A)}) + Li_3(e^{2\pi i(mU+A)})\right]$$

$$f(A,U) = 4\sum_{i,j} N_i N_j \left[h(A_i - A_j, U) + h(-A_i + A_j, U) - h(A_i + A_j, U) - h(-A_i - A_j, U)\right]$$
$$+ 64\sum_i N_i\left[h(A_i, U) + h(-A_i, U)\right]$$
$$- 4\sum_i N_i\left[h(2A_i, U) + h(-2A_i, U)\right]$$

Marcus Berg
(KITP)

M. Haack
B. Körs

ORIENTIFOLD PREPOTENTIALS

$$E_2(A,U) = \sum \frac{(U-\bar{U})^2}{|n+mU|^4} \exp\left(2\pi i\, \frac{A(n+m\bar{U}) - \bar{A}(n+mU)}{U-\bar{U}}\right)$$

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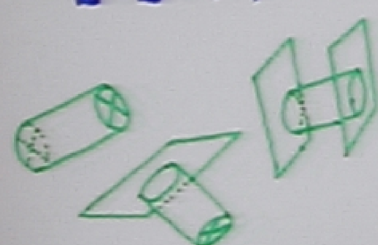
$$U_2 \mathcal{E}_2(A,U) = 2f + 2\bar{f} - (U-\bar{U})(\partial_U f - \partial_{\bar{U}} \bar{f}) - (A-\bar{A})(\partial_A f - \partial_{\bar{A}} \bar{f})$$



String propagation on bouncing cosmologies

- Andrew Tolley (Princeton)

Question

Are bouncing cosmologies possible in string theory? (bounce = E-frame collapse → expans.)

Approach

Assume existence of weak coupling bouncing solutions to string RG eqns (eg α' effects regulate singularity), look at what happens from the perspective of worldsheet physics

Observation: Near singularity (as $a \to 0$) there is a strong analogy between strings on generic anisotropic cosmologies

$$ds^2 = a_1^2(t)(-dt^2 + dx_1^2) + \sum_{i=2}^{9} a_i^2 dx_i^2$$

direction that contracts most rapidly

and plane waves

$$ds^2 = 2a_1^2(u)\, du\, dv + \sum_{i=2}^{9} a_i^2(u)\, dx_i^2$$

Physical effect: STRING MODE EXCITATION

Spacetime versus worldsheet physics

$ds^2 = -dt^2 + a^2 d\vec{x}^2$

Spacetime eg scalar field

$$\ddot\phi + 3H\dot\phi + \frac{k^2}{a^2}\phi = 0$$

$\lambda_{phys} = a\lambda_{com} = \frac{2\pi a}{k}$

Horizon at $l_c = H^{-1}$

If $\lambda_{phys} \ll l_c$ $\quad \phi \sim \frac{1}{a^{3/2}} e^{-i\omega\eta}$ $\quad dt = a\,d\eta$

If $\lambda_{phys} \gg l_c$ $\quad \phi \sim A + B\int \frac{1}{a^3} dt$

Worldsheet $\quad S = \frac{1}{4\pi\alpha'}\int d^2\sigma \sqrt{h}\left(-(\partial X^0)^2 + a^2(X^0)(\partial\vec{X})^2\right)$

$\boxed{\text{String horizon at } l_s^2/l_c}$

If $\lambda_{phys} \gg \frac{l_s^2}{l_c}$ $\quad \vec{X} \sim \frac{1}{a} e^{\pm in\sigma} e^{-in\tau}$

If $\lambda_{phys} \ll \frac{l_s^2}{l_c}$ $\quad \vec{X} \sim \vec{X}_0(\sigma) + \vec{P}_0(\sigma)\int \frac{1}{a^2} d\tau$

Note: Expansion from beginning of inflation $= e^{60} 10^{28} \sim 10^{54}$

All physics inside current horizon had $\lambda_{phys} < l_s$ at beginning of inflation

String mode excitation

On cosmological spacetimes, worldsheet vacuum $|0\rangle$ is ambiguous (analogous to QFT on curved spacetimes)

Define $|in\rangle$ and $|out\rangle$ vacua by

$$\lim_{\tau \to -\infty} X^{+\mu} \sim \frac{1}{a} e^{-in\tau} \Rightarrow |in\rangle$$

$$\lim_{\tau \to +\infty} X^{+\mu} \sim \frac{1}{a} e^{-in\tau} \Rightarrow |out\rangle$$

In general $|in\rangle \neq |out\rangle$

$$X^+_{in} = \alpha(n) X^+_{out} + \beta(n) X^-_{out}$$

Strings emerge in excited states!!

(analogous to particle creation)

$$N = \sum_{n=1}^{\infty} |\beta(n)|^2 =$$ average string level no. seen by out observer

Strings become excited when

$$\lambda_{phys} \sim l_s^2 / l_c$$

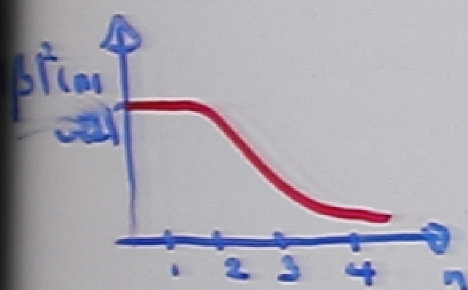
eg when universe bounces at string scale

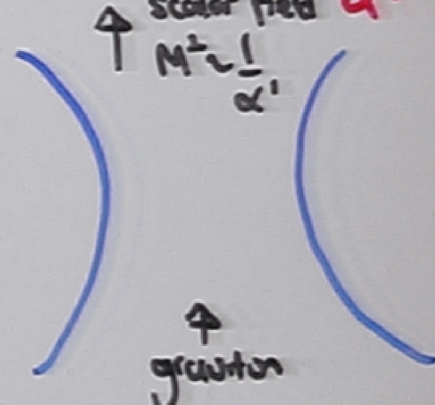
Conclusions

- Bouncing string cosmologies fall into two classes
  - → string propagation is weakly sensitive to bounce
  - → string propagation is strongly sensitive to bounce

- For generic wavelengths, strings emerge from bounce in mildly excited states

Every string emerges with $\langle M^2 \rangle \sim \frac{1}{\alpha'}$





- Excited String states could produce significant backreaction ⇒ perhaps bounce not possible

- Relevant for PBB / Ekpyrotic / Cyclic cosmologies

String Creation in

Cosmologies with a

Time-varying Dilaton

- hep-th/0402156

J. Friess, S. Gubser, I. Mitra

Background Solution

- Begin with bosonic part of 11-D SUGRA action:

$$S = \int d^{11}x \sqrt{g} \left[R - \tfrac{1}{2} G_4^2 \right]$$

- Ansatz chosen so that IIA reduction involves only NS-NS fields

$$ds_{11}^2 = -e^{2A} dt^2 + e^{2B} d\vec{x}^2 + e^{2C} dy_i^2 + e^{2D} dz^2 \; ; \; A, B, C, D \text{ depend on } t$$

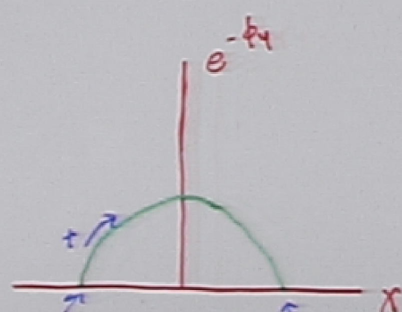
$$G_4 = h \; dx_1 \wedge dx_2 \wedge dx_3 \wedge dz$$

- 11-D solution is a one-parameter family (q) - ~~...~~
  4-D Einstein frame is q-independent:

$$ds_{4E}^2 = -d\tau^2 + \tau^{2/3} d\vec{x}^2$$

- 11-D "brane separation"/10-D string coupling is q-dependent.

- For $d\chi = e^{-\phi} *_4 H_3$, $\phi_4 = 2\phi_{10} - \frac{1}{2} \log \det g_6(y)$; $\tau = \chi + i e^{-\phi_4}$



Expected String Production

- Want to consider effective field theory approach to string creation

$$(-\Box + m^2 + \xi R)\,\varphi = 0$$

- For $q = 3 \pm \sqrt{6}$, 10-D string frame metric simplifies:

$$ds_{10}^2 = \tfrac{1}{2}\left[1 + (ht)^2\right](-dt^2 + d\vec{x}^2) + (ht)^{\sqrt{2/3}}\, dy_i^2$$

- For KK zero modes, & for $m \gg h$, wave equation simpl[...]s also:

$$\Rightarrow \left[\partial_t^2 + k^2 + \frac{m^2}{2}(1 + h^2 t^2) + \tilde{\xi}\,\frac{1}{t^2}\right]\tilde{\varphi} \approx 0 \Leftarrow$$

$$\tilde{\xi} = (7 - 2\sqrt{6})\,\xi + \sqrt{3/2} - 3/2 \qquad \varphi = \frac{1}{ab^3}\, e^{i\vec{k}\cdot\vec{x}}\,\tilde{\varphi}$$

- Solutions to this equation are exact - resulting Bogolubov coefficient:

$$|\beta|^2 = \frac{1}{2\sinh(2\pi|\mu|)}\left[e^{-2\pi|\lambda|} + e^{-2\pi|\mu|}\right]$$

$$|\lambda| = \frac{(k^2 + m^2/2)}{2\sqrt{2}\, mh} \qquad |\mu| = \frac{\sqrt{1 - 4\tilde{\xi}}}{4}$$

- For large m, $|\beta|^2$ approaches a constant. Hence, when integrated over Hagedorn density of states, string production is <u>infinite</u>.
  It can be shown that this applies for general q.

$\Rightarrow$ Backreaction of created strings is important! $\Leftarrow$

Backreaction of Created Strings

- Divergent production likely due to initial singularity
- Can account for stringy backreaction with free energy in action:

$$S = \int d^{10}x \sqrt{g}\left[e^{-2\phi}\left(R + 4(\nabla\phi)^2 - \tfrac{1}{2}H_3^2\right) + F(\text{scale factors, temperature})\right]$$

- Solutions to resulting equations of motion involve dimensionful quantities that go to infinity at early times, i.e.,

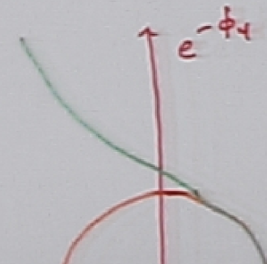
$$\sqrt{g}\, H_3^2\, \alpha' \longrightarrow \infty \qquad \frac{d\phi}{dt}\sqrt{\alpha'} \to \infty$$

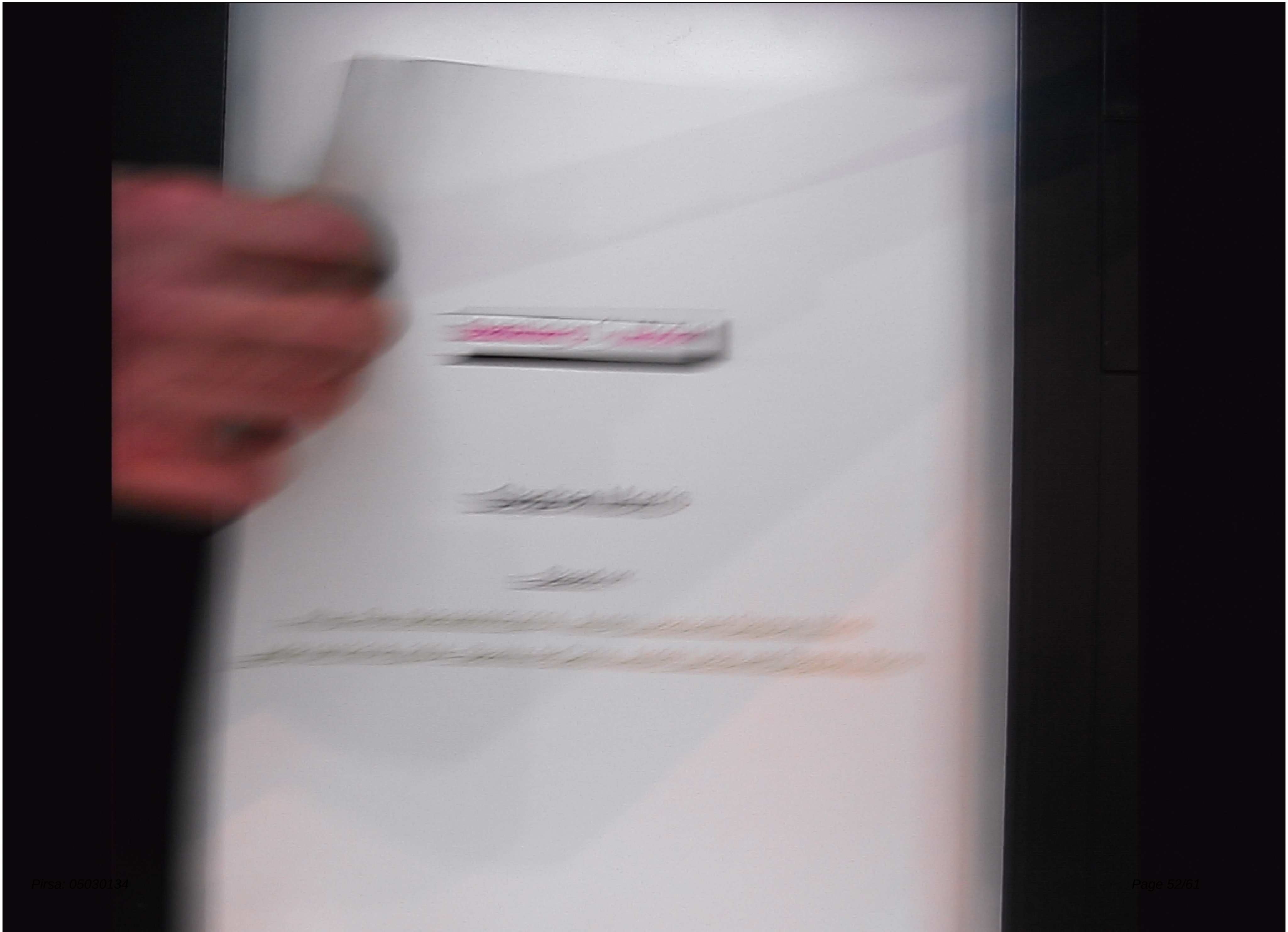
- Conjectured "solution" – If we assume:
  (1) Scale factor on compact manifold is constant
  (2) Dimensionful quantities saturate near the string scale at early times

$\Rightarrow$ Can find early time "solution" with

$$ds^2_{str} = -d\tau^2 + e^{H\tau} d\bar{x}^2 + dy_i^2 \,, \quad H \sim \frac{1}{\sqrt{\alpha'}}$$

$$\rho = e^{-\dot{\varphi}_\infty t}\rho_0 \qquad \phi_4 = \phi_0 + \dot{\varphi}_\infty t \,, \quad \dot{\varphi}_\infty = \text{constant} < 0$$





- Compactifications of M-theory on G_2 holonomy manifolds give $N = 1$ supersymmetric four-dimensional theories.
- We consider compact examples constructed by Joyce that are based on orbifolds of seven dimensional tori e.g. $T^7/\mathbb{Z}^3$. The orbifold singularities can be blown-up and replaced by two-cycles.
- There're two sets of moduli, $T^I = t^I + i\tau^I$, which describe the overall size of the torus, and $U^i = u^i + i\nu^i$, which describe the size and orientation of the blow-ups.
- The Kähler potential has the form

$$K = \sum_I \log(t^I) + \sum_i \frac{u^{i^2}}{t^{A(i)} t^{B(i)}} + c \qquad (1)$$

- The superpotential from flux and membrane instantons is

$$W = \sum_I m_I T^I + k_I e^{-T^I} + \sum_i \mu_i U^i + l_i e^{-U^i} \qquad (2)$$

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- We consider compact examples constructed by Joyce that are based on orbifolds of seven dimensional tori e.g. $T^7/\mathbb{Z}^3$. The orbifold singularities can be blown-up and replaced by two-cycles.
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- The superpotential from flux and membrane instantons is

$$W = \sum_I m_I T^I + k_I e^{-T^I} + \sum_i \mu_i U^i + l_i e^{-U^i} \qquad (2)$$

- SUSY minima with vanishing cosmological constant are found at $\frac{dW}{dT^I} = \frac{dW}{dU^i} = W = 0$. That is when

$$T^I = \ln\left|\frac{k_I}{m_I}\right| + \pi i n_I \quad (3)$$

$$U^i = \ln\left|\frac{l_i}{\mu_i}\right| + \pi i n_i \,, \quad (4)$$

and

$$\sum_I m_I\left(1+\ln\left|\frac{k_I}{m_I}\right|\right) + \sum_i \mu_i\left(1+\ln\left|\frac{l_i}{\mu_i}\right|\right) = 0$$

$$\sum_I m_I n_I + \sum_i \mu_i n_i = 0\,.$$

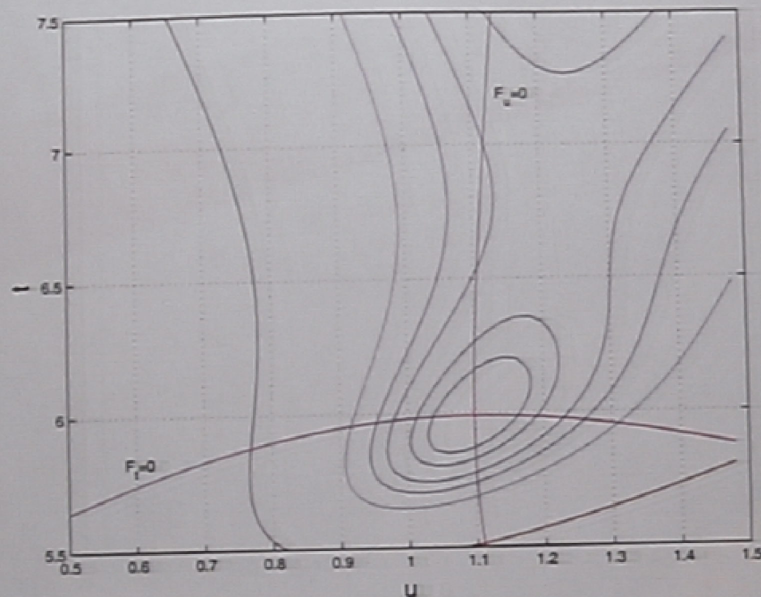
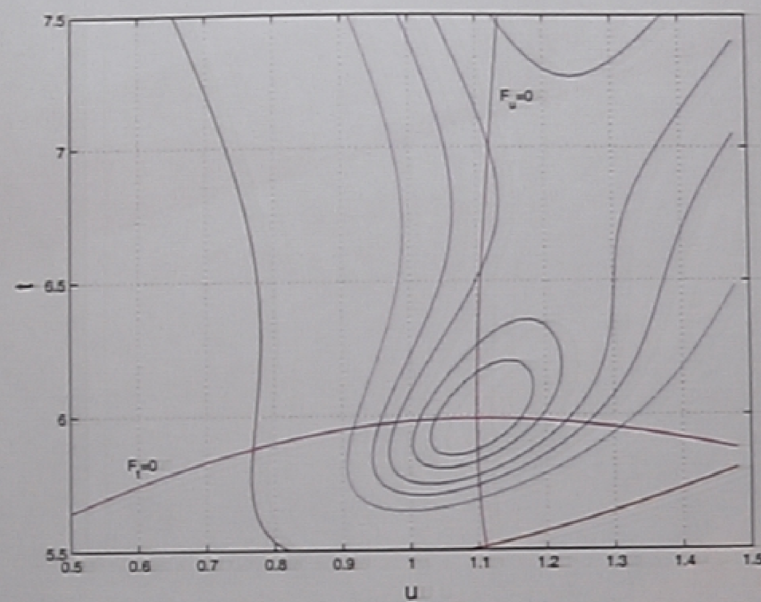


Figure 1: Contour plot of the potential in the t, u plane, for $m = 3$, $k = 1200$, $\mu = -10$, $l = -30$. We have also plotted the conditions $F_T = F_U = 0$ in order to show the supersymmetric character of the minimum. The imaginary parts of all fields have been set to zero.



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- SUSY minima with negative cosmological constant can be found at

$$u \simeq \ln\left|\frac{l}{\mu}\right| \;, t \sim \ln|\frac{k}{m}| \qquad (5)$$

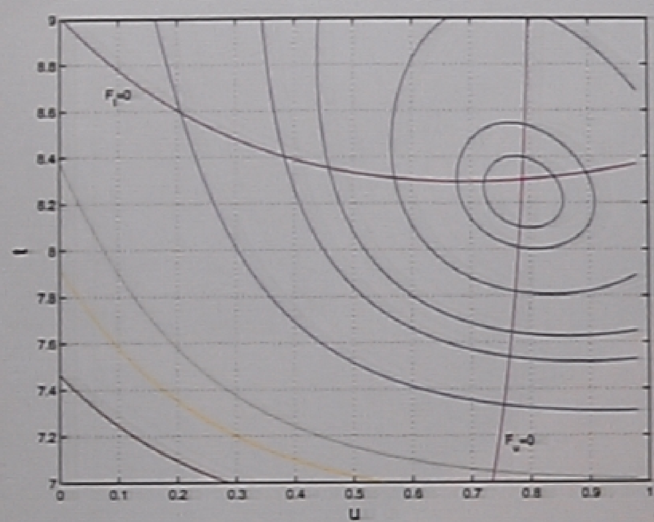

Figure 2: Contour plot of the potential, in the $(t,\ u)$ plane, for $m = -1$, $k = 1000$, $\mu = 3$, $l = 6$. We also plot the conditions $F_T = F_U = 0$ to show the supersymmetric character of the minimum. The imaginary parts of all fields have been set to zero.

- Minima with broken SUSY can also be found (close to $F_T = 0$). One is shown below

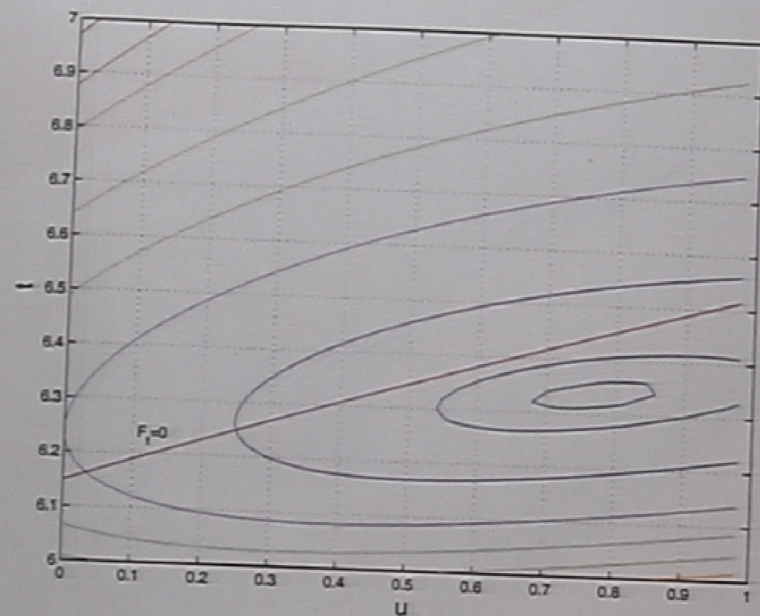

Figure 3: Contour plot of the potential, in the $(t,\ u)$ plane, for $m = -1$, $k = 1000$, $\mu = 1$, $l = -1.5$. We have also added the condition $F_T = 0$. The imaginary parts of all fields have been set to zero, where we have a minimum.

- SUSY minima with negative cosmological constant can be found at

$$u \simeq \ln\left|\frac{l}{\mu}\right| \; , t \sim \ln\left|\frac{k}{m}\right| \qquad (5)$$

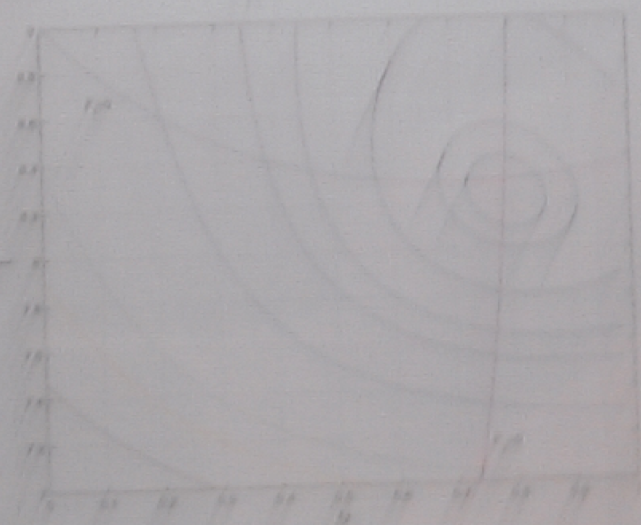

Figure 2: Contour plot of the potential, in the (t, u) plane, for $m = -1$, $k = 1000$, $\mu = 3$, $l = 6$. We also plot the conditions $F_T = F_U = 0$ to show the supersymmetric character of the minimum. The imaginary parts of all fields have been set to zero.