Title: Moduli Stabilization in String Gas Cosmology

Date: Mar 30, 2005 10:35 AM

URL: http://pirsa.org/05030143

Abstract:

Moduli Stabilization in String Gas Cosmology

Refs.: hep-th/0502069 S. Patil & R.B.

hep-th/0501032 R.B., E. Cheung & S. Watson

also

hep-th/0307044 S. Watson & R.B.

hep-th/0401037 S. Patil & R.B.

1. String Gas Cosmology

SGC: Attempt to explore consequences of string theory for cosmology in the absence of an established nonperturbative string theory

Key: make use of

* new degrees of freedom — winding modes
* new symmetries — t-duality

of string theory

N.B. ad hoc split between
classical background
stringy matter

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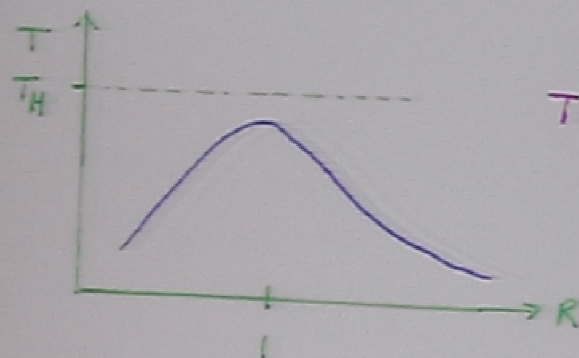
T-duality → Nonsingular Cosmology

Consider adiabatic change in R

A. Thermodynamics



$$T(R) = T\left(\frac{1}{R}\right)$$

⇒ temperature nonsingular as $R \searrow 0$

B. "Physical" Length

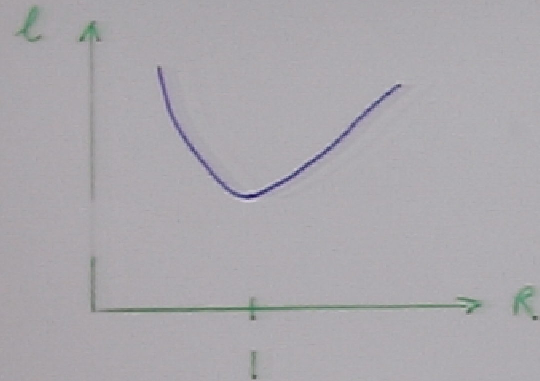
$R > 1$ ℓ measured in terms of x

$$|x\rangle = \sum_p e^{ixp} |p\rangle$$

↖ momentum eigenstates

$R < 1$ ℓ measured in terms of $\tilde{x}$

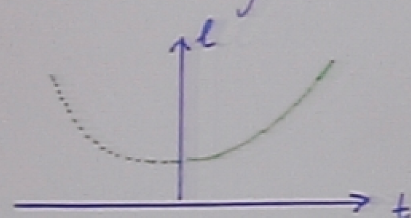
$$|\tilde{x}\rangle = \sum_{p_w} e^{i\tilde{x}p_w} |p_w\rangle$$



$\Rightarrow$ physical length nonsingular as $R \to 0$

R.B. & C. Vafa (89)

N.B. Obtain bouncing Universe!



Scenario

* Brane winding modes prevent expansion
* p branes : annihilate in $\leq d_c$ spatial dims.

$$2(p+1) = d_c + 1$$

Consider: $R(t_0) = 1$

$\dot{R}(t_0) > 0$

* Heaviest branes fall out of equilibrium first
  - largest p

no obstructions to $p = 4, \cdots$ brane annihilation

* $p = 2$ branes
  $\rightarrow d_c = 5$ expand

S. Alexander, R.B. & D. Easson (00)

* within these 5 dimensions :
  fundamental string winding modes
  $\rightarrow$ only 3 spatial dims. grow large

R.B. & C. Vafa (89)

Equations of Motion

Dilaton gravity!
(else no T-duality)

$$S = \int d^{10}x \sqrt{-g}\, e^{-2\phi}\left[R + 4\partial^\mu\phi\,\partial_\mu\phi\right]$$

$$ds^2 = dt^2 - a(t)^2 d\underline{x}^2$$

$$\lambda = \log a(t)$$

$$\varphi = 2\phi - d\lambda \qquad [d = 9]$$

$\Downarrow$ variational EOM

$$\boxed{\begin{aligned} -d\dot\lambda^2 + \dot\varphi^2 &= e^\varphi E \\ \ddot\lambda - \dot\varphi\dot\lambda &= \tfrac{1}{2} e^\varphi P \\ \ddot\varphi - d\dot\lambda^2 &= \tfrac{1}{2} e^\varphi E \end{aligned}}$$

winding modes $\to P < 0$

$\to$ confining potential for λ

Veneziano (91)
Tseytlin & Vafa (92)

duality: $\phi \to \phi - d\lambda$, $\lambda \to -\lambda$ $\Big\} \Rightarrow \varphi$ invariant

Equations of Motion

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Cosmic Loitering

R.B., D. Easson & D. Kimberly (01)

To avoid overclosure: need all winding modes in 3 large dims. to annihilate

Kibble mechanism: ≥ 1 winding mode per Hubble volume persists

$\Downarrow$

need loitering $(H=0)$

Consider R large

$\rho_w(t) = \mu \tilde{\nu}(t) t^{-2}$ winding modes

$\rho_e(t) = \gamma(t) e^{-3(\lambda(t)-\lambda(t_0))}$

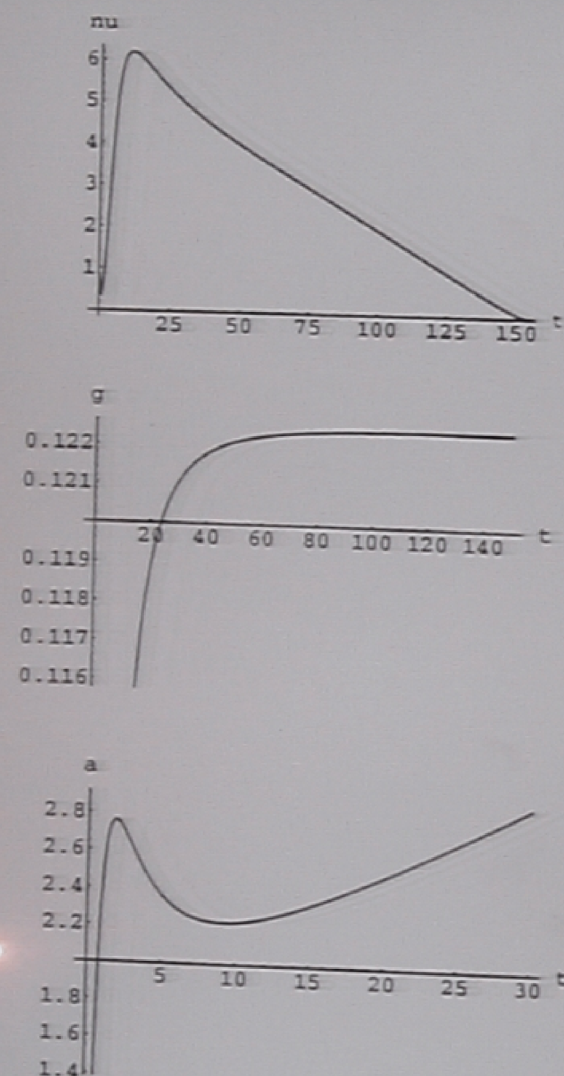
$$\boxed{\begin{aligned} \frac{d\tilde{\nu}(t)}{dt} &= 2\tilde{\nu}\left(t^{-1}-\ell\right) - cc'\tilde{\nu}^2 t^{-1} \\ \frac{d\gamma(t)}{dt} &= cc'\mu t^{-3}\tilde{\nu}^2 e^{3(\lambda(t)-\lambda(t_0))} \end{aligned}}$$

A. Vilenkin (85)

$\ell = \frac{\dot{a}}{a}$

energy transfer from winding modes to loops

see also: A. Campos (03)



R.B., D. Easson & D. Kimberly (01)

2. Moduli Stabilization

Need to stabilize:

* volume moduli R_i $i = 4, 5, \dots 9$
* shape moduli, e.g.

R_i / R_j $i, j = 4, 5, \dots 9$

ϑ_{ij} angles

* dilaton

Step 1: t-duality S. Watson & R.B.

$\downarrow$

radion stabilization in string frame

$R_i \to 1$ $i = 4, 5, \dots 9$

Step 2: t-duality + massless states

at self-dual radius

$\downarrow$

radion stabilization in Einstein frame

step 3 : t-duality & massless states
& fluxes

$$\downarrow$$

$$\theta_{ij} = \frac{\pi}{2}$$

R.B., E. Cheung & ~~R.B.~~ S. Watson

step 3 : t-duality & massless states

& fluxes

$$\downarrow$$

$$\vartheta_{ij} = \frac{\pi}{2}$$

R.B., E. Cheung & ~~R.B.~~ S. Watson

S. Watson & R.B. (03)

Radion Stabilization

Q: How does radius of "small" dimensions evolve once the 3 "large" dimensions are expanding?

Ansatz: $ds^2 = dt^2 - e^{2\lambda} d\underline{x}^2 - e^{2\nu} d\underline{y}^2$

$\uparrow$

$\mathbb{R}^3$ large $\quad \mathbb{R}^6$ small

Dilaton gravity action + perfect fluid matter

$$-3\ddot{\lambda} - 3\dot{\lambda}^2 - 6\ddot{\nu} - 6\dot{\nu}^2 + 2\ddot{\phi} = \frac{1}{2} e^{2\phi} \rho$$

$$\ddot{\lambda} + 3\dot{\lambda}^2 + 6\dot{\lambda}\dot{\nu} - 2\dot{\lambda}\dot{\phi} = \frac{1}{2} e^{2\phi} p_\lambda$$

$$\ddot{\nu} + 6\dot{\nu}^2 + 3\dot{\lambda}\dot{\nu} - 2\dot{\nu}\dot{\phi} = \frac{1}{2} e^{2\phi} p_\nu$$

$$4\ddot{\phi} - 4\dot{\phi}^2 - 12\dot{\lambda}\dot{\phi} - 24\dot{\nu}\dot{\phi}$$
$$+ 3\ddot{\lambda} + 6\dot{\lambda}^2 + 6\ddot{\nu} + 21\dot{\nu}^2 + 18\dot{\lambda}\dot{\nu} = 0$$

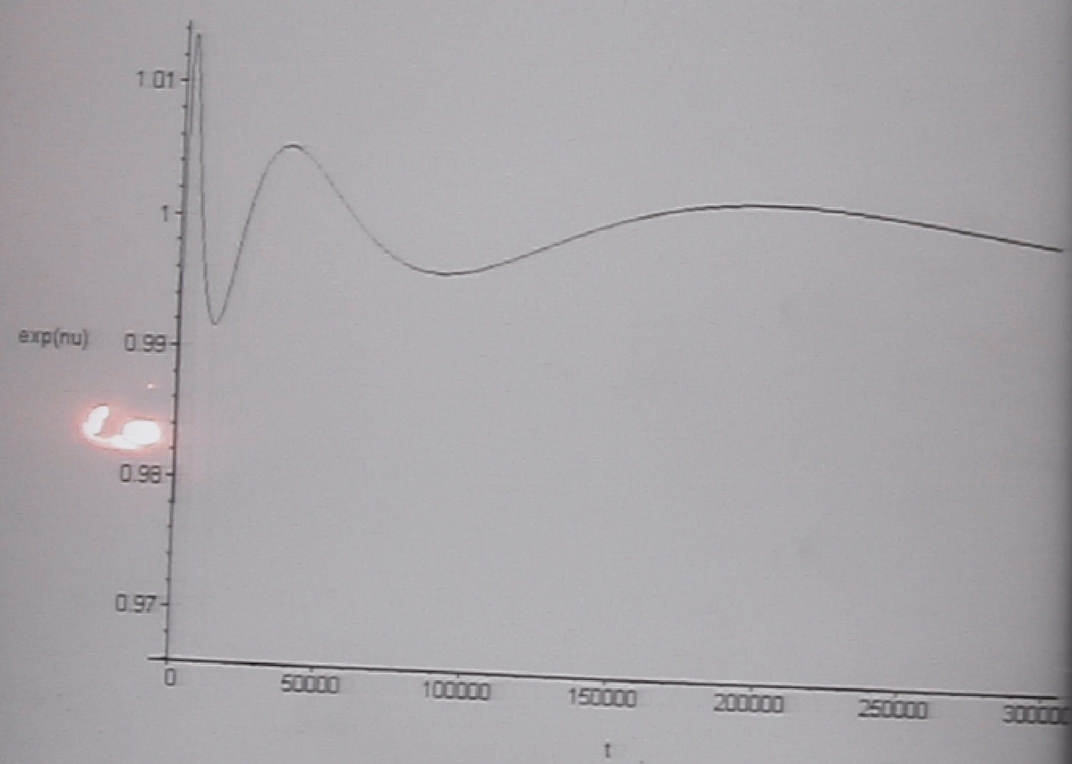
Matter (string gas) sources obeying T duality

$\downarrow$

include equal number of winding and

radion stabilization

S. Watson & R.B. (03)



S. Patil & R.B. (04, 05)

Radion Stabilization at Late Times

Q: Does the radion remain stabilized after the dilaton is fixed?

Model: GR + string gas
winding & momentum modes about extra dims.
gas of radiation in 3+1 dim.

$$ds^2 = dt^2 - a(t)^2 d\underline{x}^2 - \underbrace{b(t)^2 d\underline{y}^2}_{\sum_{i=4}^{9} b_\alpha(t)^2 dy_\alpha^2}$$

$$\ddot{b}_\alpha + \dot{b}_\alpha \left(\sum_{j=1}^{3} \frac{\dot{a}_j}{a_j} + \sum_{\substack{c \neq \alpha \\ c=4}}^{9} \frac{\dot{b}_c}{b_c} \right) = \sum_{n,w} 8\pi G \frac{\mu_{n,w}}{\sqrt{g}\, \varepsilon_{n,w}} S$$

$$S = \left(\frac{n_\alpha}{b_\alpha}\right)^2 - w_\alpha^2 b_\alpha^2 + \frac{2}{D-1}\left[(w,w) + (n,w) + 2(N-1) \right]$$

vanishes for massless modes

Note: $\mu_{n,w}$ # densities $\quad$ n momentum #
$\varepsilon_{n,w}$ energies $\quad$ w winding #

R.B., E. Cheung & S. Watson (05)

Shape Moduli Stabilization

Simplifications: 1) $CY^3 \to T^6 \to T^2$

2) freeze all moduli except for angle of T^2

$$ds^2 = dt^2 - dx^2 - G_{nm}\, dy^n dy^m$$

$$G_{nm} = \begin{pmatrix} 1 & \sin\vartheta \\ \sin\vartheta & 1 \end{pmatrix}$$

add flux about T^2:

$$B_{nm} = \begin{pmatrix} 0 & b(t) \\ -b(t) & 0 \end{pmatrix}$$

Consider xy & tt Einstein equations

$$-\frac{1}{4}\dot{\vartheta}^2 - \frac{1}{2}c + \frac{\dot{b}^2}{4G} = e^{-2\phi}\varepsilon$$

$$-\frac{1}{2}\frac{1+S_\vartheta^2}{S_\vartheta C_\vartheta}\ddot{\vartheta} + \frac{1}{4}\dot{\vartheta}^2 + \frac{1}{2}c - \frac{\dot{b}^2}{4G} = e^{-2\phi} S_\vartheta^{-1}\tau$$

where $T_{\mu\nu} = \begin{pmatrix} \varepsilon & 0 & 0 \\ 0 & -p & -\tau \\ 0 & -\tau & -p \end{pmatrix}$

Matter = massless string states

$\rightarrow \varepsilon(\vartheta),\ \tau(\vartheta)$

Combine eqs.:

$$\ddot{\vartheta} + 8(1+b^2)\,k^{-1/2}\,e^{-2\phi}\,\vartheta = 0$$

$\Rightarrow$ stable fixed point $\vartheta = 0$

Note: $k = 4 + b^2 + 2N$

$c = \dfrac{26-D}{6}$

generalization to conformal CY^3:

E. Cheung, P. Langfelder

in preparation

N.B. dilaton is also stabilized

Conclusions

String Gas Cosmology provides indication that

* Cosmological singularity resolved
* Only 3 spatial dimensions become large
* moduli stabilized

volume modulus: easy

consequence of t-duality, new stringy states

shape moduli:

dynamically stabilized

Note: Considerations are completely dynamical

Workshop on String Gas Cosmology

April 30 & May 1 2008

McGill University

contacts: R. Brandenberger
J. Cline
H. Stoica

rhb@hep.physics.mcgill.ca

Acceleration from Gravitational Back-Reaction

E. Kolb, S. Matarrese, A. Notari & A. Riotto

hep-th/0503117

Assumption: $\Lambda_0 = 0$

Acceleration from Gravitational Back-Reaction

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hep-th/0503117

Assumption: $\Lambda_0 = 0$

or

Dynamical Relaxation of Λ by Gravitational Back-Reaction

Assumption: Λ_0 large, driving inflation

Final state: dynamical fixed point with $\Omega_{\Lambda_{eff}} \sim \frac{1}{2}$

R.B. hep-th/0210165

Kolb et al. Argument

Ass: * Einstein gravity
* only regular matter (obeying SEC)
* existence of a large phase space of super-Hubble modes (such as provided by inflation)
* $\Lambda_0 = 0$

Claim: * long wavelength fluctuations effect locally measured q_0
* large variance in q_0
* If we are in an underdense region then $q_0 < 0$ possible

Note: * does not solve cosmol. constant problem
* does not solve coincidence problem
* no need for dark energy

NB leading effect is 2^{nd} order (1-loop)

History of Back-Reaction Work

N. Tsamis & R. Woodard: Phys. Lett. B 301, 351 (1993)

pure gravity, $\Lambda_0 > 0$

2 loop back-reaction of IR modes

$\rightarrow$ relaxation of Λ

V. Mukhanov, L. Abramo & R.B. gr-qc/9609026

L. Abramo, R.B., V. Mukhanov gr-qc/9704037

gravity + matter, $\Lambda_0 > 0$

1 loop back-reaction of IR modes

$\rightarrow$ negative contribution to Λ

R.B. dynamical relaxation of Λ

dynamical fixed pt. with $\Lambda_{\Lambda_{eff}} \sim \frac{1}{2}$

W. Unruh astro-ph/9802323

G. Geshnizjani & R.B. gr-qc/0204074

hep-th/0310265

leading non-gradient IR back-reaction

terms only locally ...

G. Geshnizjani & N. Afshordi : gr-qc/0405117

leading IR gradient terms are locally measurable even in the absence of entropy perturbations

but small in general

Kolb et al. hep-th/0503117

leading IR gradient terms can be large

(if spectrum of flucts. is red)

leads to negative q_0 for some regions of space

Common Objections

Super-Hubble modes cannot effect local physics by causality

wrong !!

causal horizon >>> Hubble radius H^{-1}

in inflationary cosmology

Violates locality

wrong !!

the effect of IR modes can be encoded in local FRW equations

R.B. & C.S. Lam, hep-th/0407048

non-gradient IR terms

$\Downarrow$

local renormalization of $\begin{cases} \Lambda \\ k \end{cases}$

Specific Objections

G. Geshnizjani, D. Chung & N. Afshordi astro-ph/0503553

* effect of Kolb et al. terms is a local rescaling of k
* such rescalings of k are bounded to be very small by CMB observations

E. Flanagan hep-th/0503202

* q_0 cannot change sign without having a fluid violating SEC

C. Hirata & U. Seljak astro-ph/0503582

* q_0 cannot change sign without having a fluid violating SEC
* causality limits magnitude of IR back-reaction effects in models with only adiabatic fluctuations

D. Wiltshire gr-qc/0503099

* specific exactly soluble model

Personal & Developing View

Specific Back-reaction scenario of Kolb et al.
may not work

Objections do not affect attempts to use
back-reaction to solve cosmological
constant problem