Title: Backreaction in Closed String Tachyon Condensation

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Abstract: Working in the weak tachyon region of a condensing tachyon background, we find the modified equations of motion for massless strings with conformal perturbation theory. We then estimate the backreaction on the background dilaton. In large (supercritical) dimensions, we find that the backreaction can be significant in a large region of spacetime.

Backreaction in Closed String Tachyon Condensation

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Based on arXiv:0805.0570

Stringy Models of Cosmology

To understand how stringy cosmology, need time-dependent models

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Linear Dilaton CFT

Running of scalar field

- Exact in α' (but has strong coupling region)

$$G^s_{\mu\nu} = \eta_{\mu\nu} \ , \quad \Phi = \Phi_0 + V_\mu X^\mu$$

- Einstein frame is FRW (quintessence-like)
- Dilaton running tied to (supercritical) dimensionality

$$V_\mu V^\mu = \frac{26 - D}{6\alpha'}$$

Stringy Models of Cosmology

String theory is also flush with tachyons

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Open String Tachyons

- Decay of unstable D-brane (or pair)
- Relevant to brane inflation
- Ultimately less tied to gravity

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Closed String Tachyons

Example: Bosonic string

- Lowest closed string mode $m^2 = -4/\alpha'$
- All of spacetime unstable
- Condensed tachyon removes entire dimensions of space

Bulk Tachyon: Worldsheet Picture

Condensing Tachyon Background

"Perturb" linear dilaton background by tachyon expectation

- Tachyon obeys EOM

$$\partial \cdot (\partial - 2V)T = -4/\alpha' T$$

- Two similar solutions of interest

$$T = \pm \frac{\mu^2}{2\alpha'} e^{\beta X^0} (X^a)^2 + \cdots \ , \quad \beta \approx -2/\alpha' V_0$$

$$T = \pm \frac{\mu^2}{2\alpha'} e^{\beta X^+} (X^a)^2 + \cdots \ , \quad \beta = -2/\alpha' V_-$$

- α' corrections suppressed at large D; lightlike case α' exact

Bulk Tachyon: Worldsheet Picture

Worldsheet Interpretation

- Acts as a worldsheet potential

$$S_{ws} = -\frac{1}{4\pi\alpha'}\int d^2\sigma \left[\partial_\alpha X^\mu \partial^\alpha X_\mu + T(X) \right]$$

- Spatial dimensions "confined" by potential
- Worldsheet RG flow to linear dilaton with fewer dimensions

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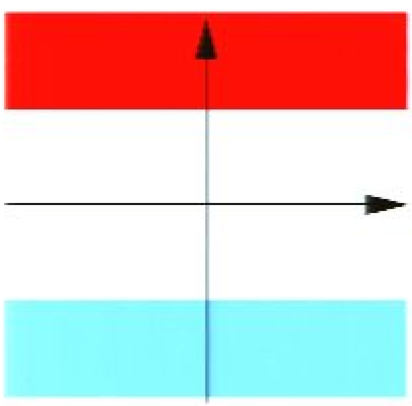
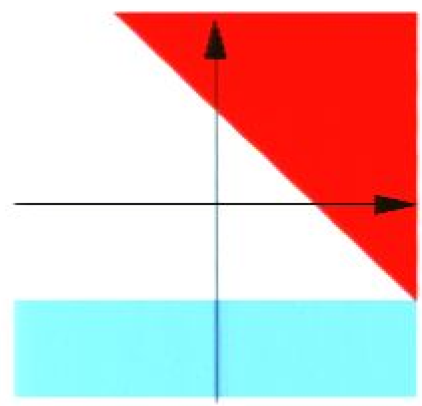


Timelike tachyon



Lightlike tachyon

Cosmology of the Bulk Tachyon

Questions from the Spacetime Perspective

- Two discrete cosmologies (tachyonic vs lower-dimensional)
- Strings can't penetrate large tachyon region
  What about massless fields?
- Difficulties deriving the spacetime action with tachyon
- Behavior of fluctuations?
  If this replaces Big Bang, relates to trans-Planckian problem

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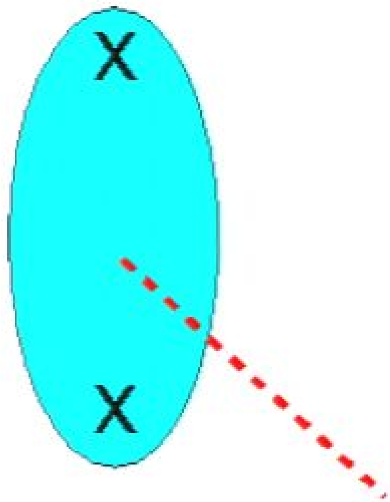
To Address Today

- Equation of motion for massless fields in weak tachyon background
- Quantum fluctuations and backreaction of those fields
- Approach through well-understood worldsheet theory

Deriving Equations of Motion

For small tachyon, we have linear dilaton plus external source
Look for response of massless fields to tachyon source



Scattering from Tachyon Background

- Tachyon background just a collection of tachyon particles
- Leading change to massless field propagation from scattering off one tachyon
- Scattering amplitude $\rightarrow$ quadratic action

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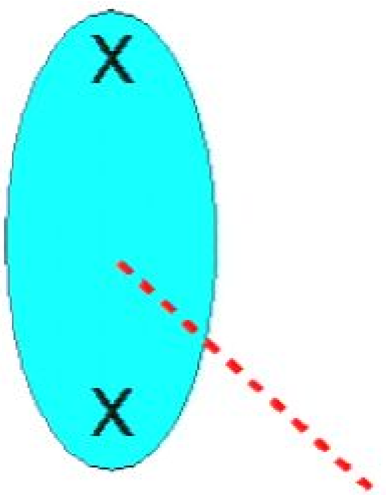

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Long-wavelength Limit

- Add opposite moving plane waves, subtract spatially uniform tachyon
- Take $\vec{k} \longrightarrow 0$ with $\alpha' \vec{k}^2 \mu^2 \longrightarrow \mu^2$

Deriving Equations of Motion

Combine with the EOM in the linear dilaton background:

$$0 = \Big\{ \partial \cdot (\partial - 2V) - \frac{T(X)}{4} \Big[4D + \alpha' \beta (\partial - 2V)_- + \frac{\alpha'^2 \beta^2}{4} \partial_- (\partial - 2V)_- \Big]$$

$$- \frac{\alpha' \mu^2}{16} e^{\beta X^+} \Big[N\beta (\partial - 2V)_- - \frac{N\beta}{2} (\partial - 2V)_- - \frac{N}{2} V_+ \partial_-$$

$$- \frac{N}{2} V_- \partial_+ - \partial_a \partial_a - \frac{1}{2} V \cdot (\partial - 2V) \Big]$$

$$+ \frac{\mu^2}{4} e^{\beta X^+} X^a \Big[\partial_a - \frac{\alpha' \beta}{4} (\partial - 2V)_- \partial_a - \frac{\alpha' \beta}{4} \partial_- \partial_a \Big] \Big\} \phi$$

(Similar for timelike case)

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$$-\frac{N}{2}V_-\partial_+ - \partial_a\partial_a - \frac{1}{2}V\cdot(\partial - 2V)\Big]$$
$$+\frac{\mu^2}{4}e^{\beta X^+}X^a\Big[\partial_a - \frac{\alpha'\beta}{4}(\partial - 2V)_-\partial_a - \frac{\alpha'\beta}{4}\partial_-\partial_a\Big]\Big\}\phi$$

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Mass terms (including polarization in "condensing" dimensions)

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Exponentiated drag terms

Approximate Dilaton Fluctuations

Truncating Dilaton EOM

Need something more tractable

- Drop subleading time dependence in tachyon
- In lightlike case, set lightcone derivatives to time derivatives
- Fix X^a with $(X^a)^2 \gg D\alpha'$
- Drop some spatial dependence $\partial_a \to 0$
- Take large D limit

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$$\left[\partial_x^2 + 2V\partial_x + \vec{k}^2/\beta^2 M^2 e^x \left(a + b\partial_x\right)\right]\phi = 0$$

$$x = \beta t\ ,\ \ V = |V_t|/\beta\ ,\ \ a = 4D\ ,\ \ b = 24/D\ ,\ \ M^2 = \mu^2 (X^a)^2/8\alpha'\beta^2$$

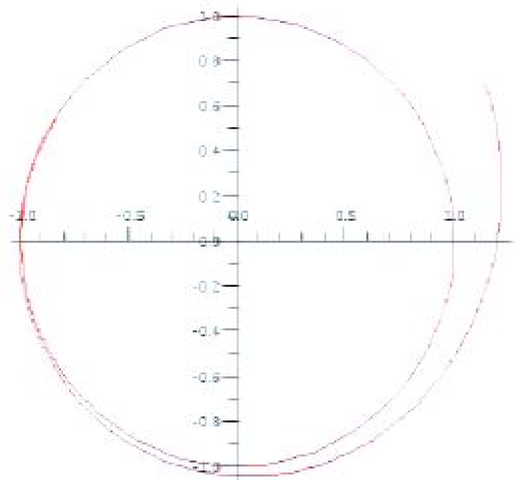
Approximate Dilaton Fluctuations

Solution

$$\phi = e^{-Vx}\left[Ae^{\nu x}M\left(\nu + a/b; 1 + 2\nu; M^2 b e^x\right) + B(\nu \to -\nu)\right]$$

$$\nu = \sqrt{V^2 - \vec{k}^2/\beta^2}$$

- M is Kummer (or confluent hypergeometric) function *aka* ${}_1F_1$
- Canonical in past, superexponential growth in future



Backreaction on Dilaton Equation

Cosmological Effect of Fluctuations?

$$V_\mu V^\mu + \nabla^2 \Phi - \partial_\mu \Phi \partial^\mu \Phi = 0$$

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- Allow fluctuation $\Phi \longrightarrow \Phi + \kappa\phi$
- Check how much "dilaton stuff" there is

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Calculating Expectation

- Choose term of ϕ to avoid large backreaction in past
- Integrate $k \leq |V_t|$ or $k \leq 1/\sqrt{\alpha'}$
  Cosmological scale vs Scale of new physics

$$\langle\kappa^2(\partial\phi)^2\rangle \approx \frac{g_s^2}{\alpha'}\left(\frac{24}{D}\right)^{D/2} I_D$$

Backreaction on Dilaton Equation

Backreaction When Tachyon Becomes Large

Tachyon becomes large when $M^2 b e^{\beta t} = \pm 1$

Dimension		72	96	120	144	168	192	216	240	360	480
$\log(I_D(24/D)^{D/2})$	$+1$	87	123	160	198	237	277	317	358	571	792
	-1	40	54	74	95	118	140	163	187	315	452

Can be quite large even when using stringy limit

Dimension		192	216	240	360	480	540	600	660
$\log(I_D(24/D)^{D/2})$	$+1$	80	90	100	151	201	226	251	277
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To avoid, tachyon must condense in extremely weak coupling

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Backreaction on Dilaton Equation

Strong Coupling, Strong Tachyon, Strong Backreaction

Conclusions

In General

- Sufficiently tractable stringy models of cosmology
- Developing tools to understand spacetime picture
- Future: Useful for effective action
- Future: More complete understanding of massless field behavior

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- Sufficiently tractable stringy models of cosmology
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In Specific

- Can estimate strength of quantum backreaction
- May be very large even for relatively small string coupling

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