Don't panic! BRST Quantization, Ghosts and Tachyon Condensation in Closed Superstring Field Theory

Lorenz Schlechter

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Don't Panic! Closed String Tachyons in ALE Spacetimes

A. Adams[1,2], J. Polchinski[2] and E. Silverstein[1,2]

[1]Department of Physics and SLAC
Stanford University
Stanford, CA 94305/94309

[2]Institute for Theoretical Physics
University of California
Santa Barbara, CA 93106

We consider closed string tachyons localized at the fixed points of noncompact non-supersymmetric orbifolds. We argue that tachyon condensation drives these orbifolds to flat space or supersymmetric ALE spaces. The decay proceeds via an expanding shell of dilaton gradients and curvature which interpolates between two regions of distinct angular geometry. The string coupling remains weak throughout. For small tachyon VEVs, evidence comes from quiver theories on D-branes probes, in which deformations by twisted couplings smoothly connect non-supersymmetric orbifolds to supersymmetric orbifolds of reduced order. For large tachyon VEVs, evidence comes from worldsheet RG flow and spacetime gravity. For $\mathbb{C}^2/\mathbb{Z}_n$, we exhibit infinite sequences of transitions producing SUSY ALE spaces via twisted closed string condensation from non-supersymmetric ALE spaces. In a T-dual description this provides a mechanism for creating NS5-branes via *closed* string tachyon condensation similar to the creation of D-branes via *open* string tachyon condensation. We also apply our results to recent duality conjectures involving fluxbranes and the type 0 string.

August 2001

Content

- BRST Quantization
- Ghosts in String Theory
- Tachyons in String Field Theory
- (Unitarity Violation)

How to quantize a theory

- Canonical Quantization ($\{\ \} \rightarrow i[\ ]$)
- Path Integral (QFT)
- BRST-Quantization (String Theory)
- BV-Quantization / Field-Antifield formulation (String Field Theory)

Path Integral

$$Z = \int \mathcal{D}\Phi e^{iS[\Phi]} \tag{1}$$

$$S_{YM} = \int \mathrm{d}^4x \; -\frac{1}{4} F^a_{\mu\nu} F^{a,\mu\nu} \tag{2}$$

$$F^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f^{abc} A^b_\mu A^c_\nu \tag{3}$$

Invariant under

$$A'_\mu = A_\mu + \frac{1}{g} D_\mu \alpha \tag{4}$$

Problems

Without gauge fixing, $Z = \infty$

$$[A^\mu(x), \dot{A}^\nu(y)] = ig^{\mu\nu}\delta(x-y) \tag{5}$$

$\rightarrow$ negative norm states from A^0!
Solution to both: Faddeev Popov trick:

$$1 = \int \mathcal{D}\alpha\delta(f(A^\alpha))det(\frac{\partial f(A^\alpha)}{\partial\alpha}) \tag{6}$$

Insert in path integral and rewrite det as integral over fermionic ghost variable c.
E.g. choose

$$f(A) = \partial^\mu A^a_\mu + w^a \tag{7}$$

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a,\mu\nu} - \frac{1}{2\xi}(\partial^\mu A^a_\mu)^2 + \overline{c}_a(-\partial^\mu D^{ab}_\mu)c_b \tag{8}$$

BRST Symmetry

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a,\mu\nu} - \frac{1}{2\xi}(\partial^\mu A^a_\mu)^2 + \overline{c}_a(-\partial^\mu D^{ab}_\mu)c_b \tag{9}$$

This is equivalent to the Lagrangian

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a,\mu\nu} + \frac{\xi}{2}(B^a)^2 + B^a(\partial^\mu A_{a,\mu})^2 + \overline{c}_a(-\partial^\mu D^{ab}_\mu)c_b \tag{10}$$

B is a purely auxiliary field! This has the symmetry

$$\begin{aligned}
\delta A^a_\mu &= \epsilon D^{ab}_\mu c^b \\
\delta c^a &= -1/2 g \epsilon f^{abc} c^b c^c \\
\delta \overline{c}^a &= \epsilon B^a \\
\delta B^a &= 0
\end{aligned}$$

This symmetry is universal in gauge theories!

BRST Symmetry

This symmetry is universal in gauge theories! The BRST charge Q_B is given by the generators of the symmetry:

$$Q_B = c^a T^a \tag{11}$$

One ghost/anti-ghost system per symmetry generator!

BRST in string theory

Symmetry $\rightarrow$ Ghost System

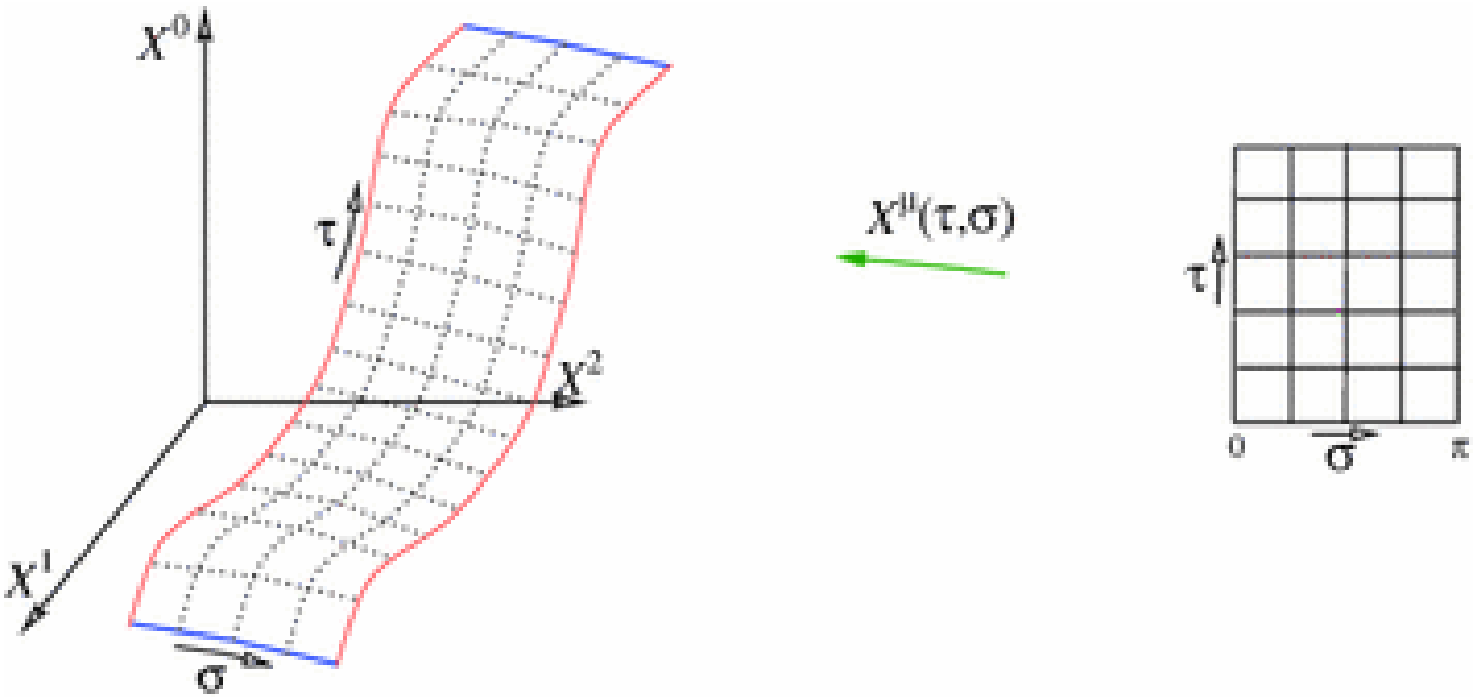
- Diffeomorphisms$\rightarrow$ bc-system
- Supersymmetry $\rightarrow$ $\beta\gamma$-system
- R-Symmetry $\rightarrow$ $\eta\xi$-system

First Order Systems

- Fermionic Scalars $\rightarrow$ ghosts
- Defined by one number λ
- Consist of two fields, ghosts c and anti-ghosts b
- Conformal dimension $(\lambda, 1-\lambda) \approx$ *spin*
- $\lambda = 1/2 \rightarrow$ two fermions
- For $\lambda > 1$ negative conformal weight $\rightarrow$ non-unitary theory

Conformal Description of the Bosonic String

- String forms an 2-dimensional world sheet (time+1-d extension)
- Action=volume of the world sheet.
- position of string in 26-d space-time is described by 26 scalar fields X^μ



- Result: 2d CFT

CFT Basics

String theory is a 2d (super)conformal theory

- CFTs are defined in terms of the energy momentum tensor T (and its superpartner G)
- The quantum algebra of the 2d conformal group is the Virasoro algebra
- The conformal symmetry has an anomaly given by the central charge c

$\rightarrow$ For consistent theory c has to vanish.

CFTs in the game

CFT	Origin	conformal dimension	c
X	Dimension	0	1
ψ	Supersymmetric Dimension	1/2	1/2
bc	Diffeomorphisms	(2,-1)	-26
$\beta\gamma$	Supersymmetry	(3/2,-1/2)	11
$\eta\xi$	R-Symmetry	(1,0)	-2

CFTs in string theory

The total energy momentum tensor and central charge are simply the sum of the single CFTs. Reminder: Need $c = 0$!
Nice: All free 2d CFTs are exactly solvable (partition function known)

The bc-System

- Always have Diffeomorphisms$\rightarrow$ bc-system.
- This has c=-26, needs to be canceled.
- Simplest way, add 26 bosons X(dimensions)$\rightarrow$ bosonic string

Partition function of the bosonic string

$$T = 26\,T_X + T_{bc} \tag{12}$$

$$Z_{open} = \frac{1}{q} + 24 + 576q + \ldots \tag{13}$$

Partition function Z counts states. The exponent of q gives the mass.

Partition function of the bosonic string

$$T = 26\,T_X + T_{bc} \tag{14}$$

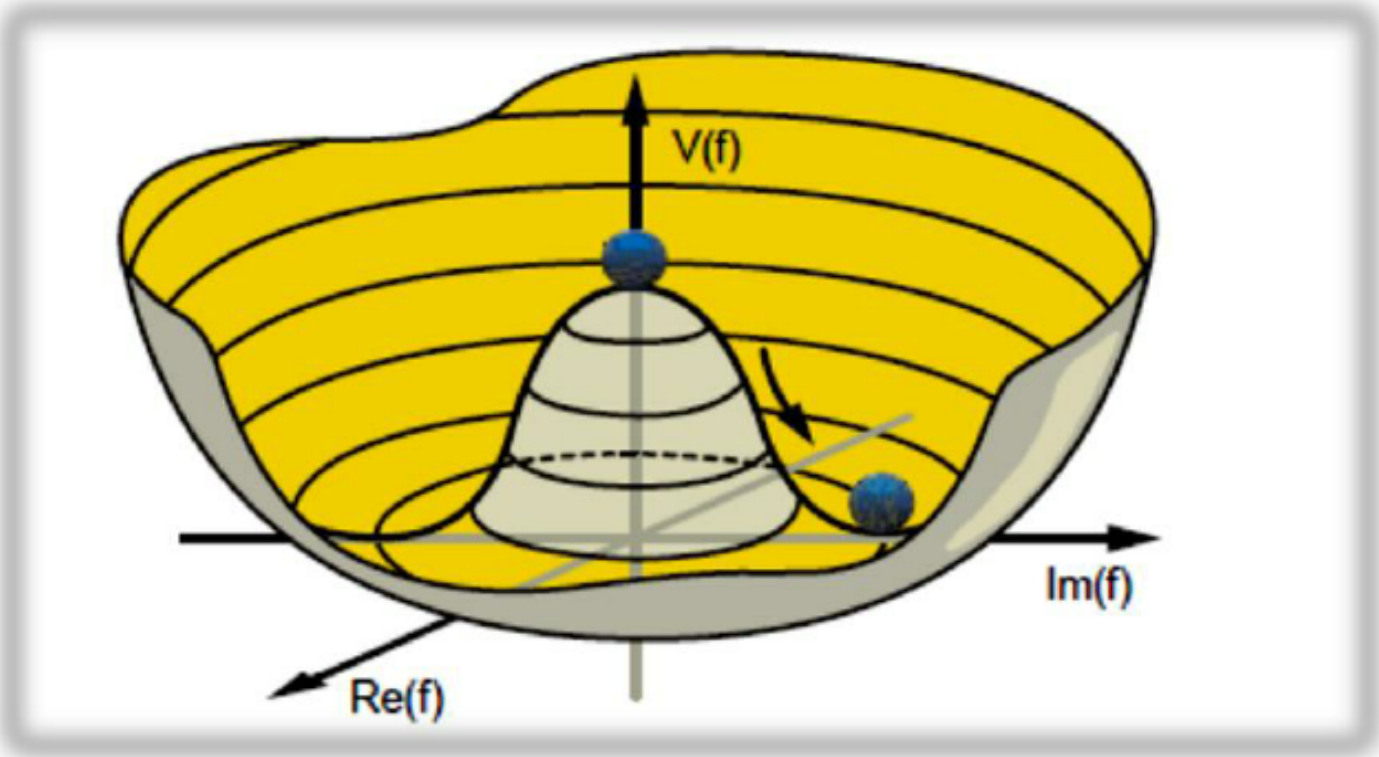
$$Z_{open} = \frac{1}{q} + 24 + 576q + \ldots \tag{15}$$

Partition function Z counts states.$\rightarrow$ tachyon

Tachyon

- Field of negative m^2
- Signals instability of the vacuum.
- Are nothing to be feared (e.g. Higgs)
- Tachyon potential V allows identification of the new vacuum.

Higgs potential

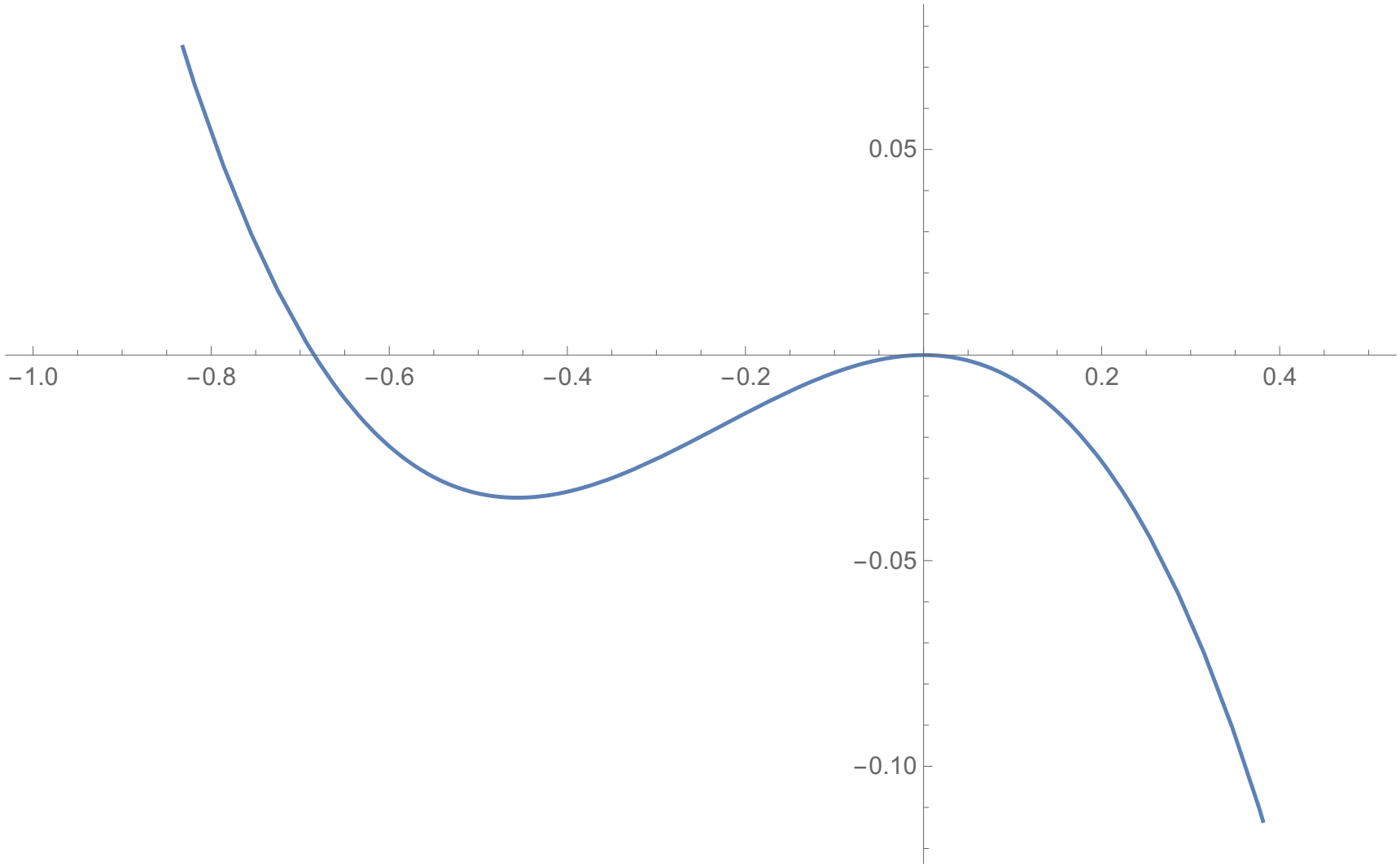


Tachyons in String Theory

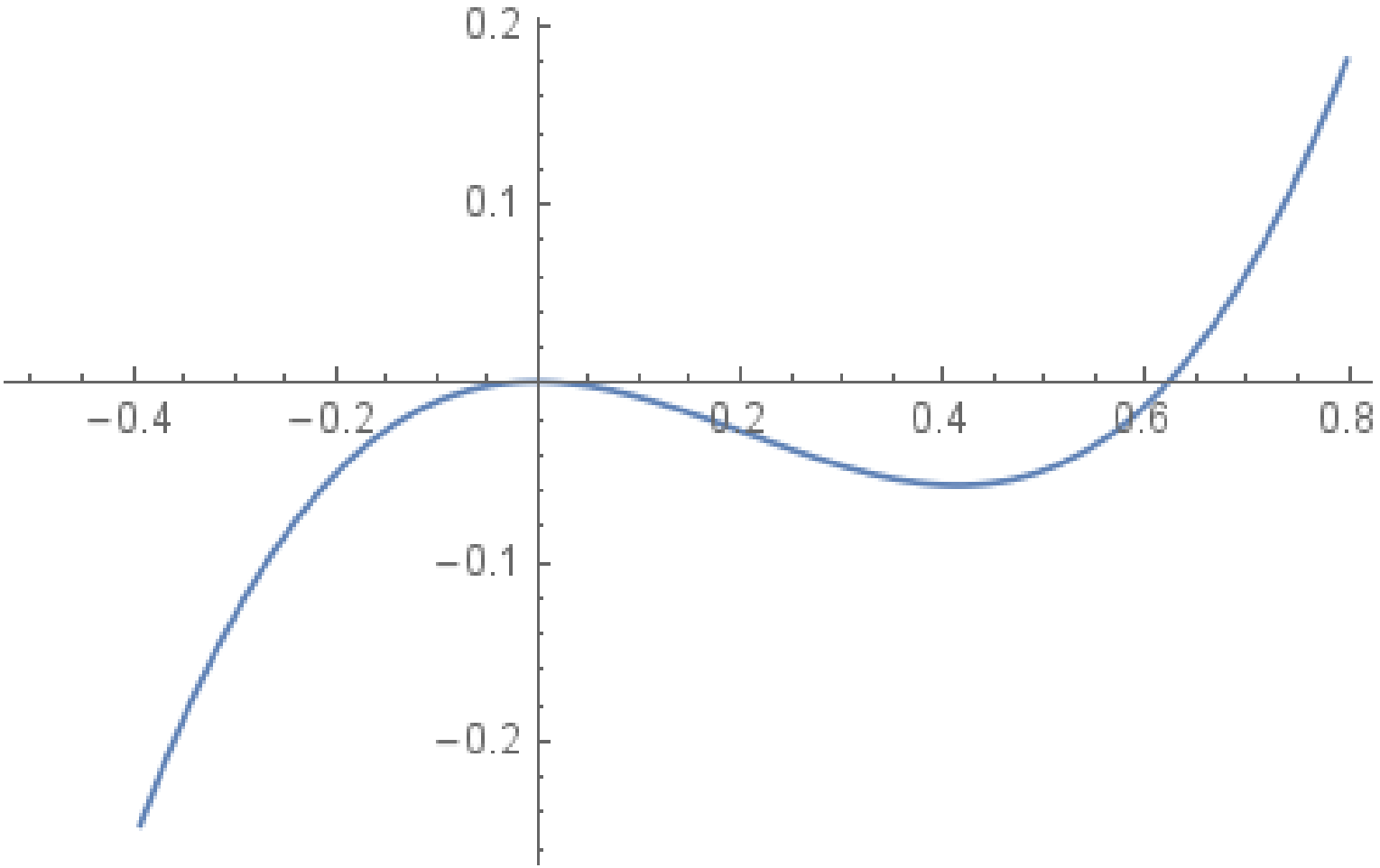
- Describe the decay of the space they are localized on
- Open string tachyons describe the decay of the D-brane they end on
- Orbifold tachyons describe the decay of the orbifold to flat space
- Bulk tachyons Describe the decay of dimensions!

$\rightarrow$ only the last one changes the theory dramatically.

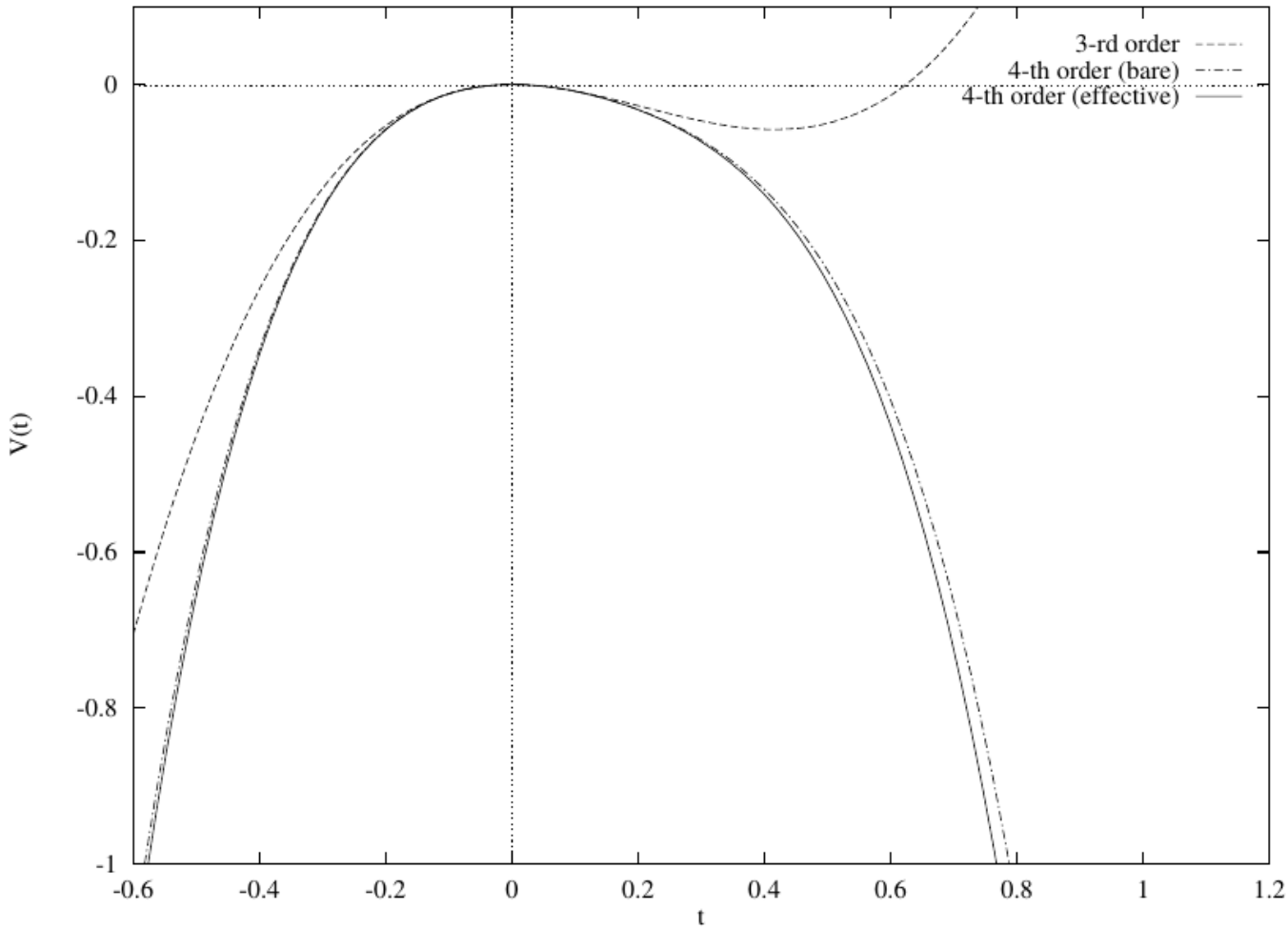
Potential of the Bosonic Open String Tachyon



Potential of the Bosonic Closed String Tachyon (cubic order)



Potential of the Bosonic Closed String Tachyon (quartic order)



Potential of the Bosonic Closed String Tachyon

- The quartic order destabilizes the vacuum!
- Quintic terms reintroduce the stable point [Moeller 2007]
- Infinite series of terms.
- Interpretation lacking.
- But bosonic string theory not a true vacuum

Getting rid of the tachyon

- Add Supersymmetry!
- Introduces $\beta\gamma$ system and a fermion for each boson X.
- $c_{ghosts} = c_{bc} + c_{\beta\gamma} = -26 + 11 = -15$
- Each dimensions adds $c = 1 + 1/2$

$\rightarrow$ critical dimension 10
Still tachyonic, but can be projected out.

More SUSY

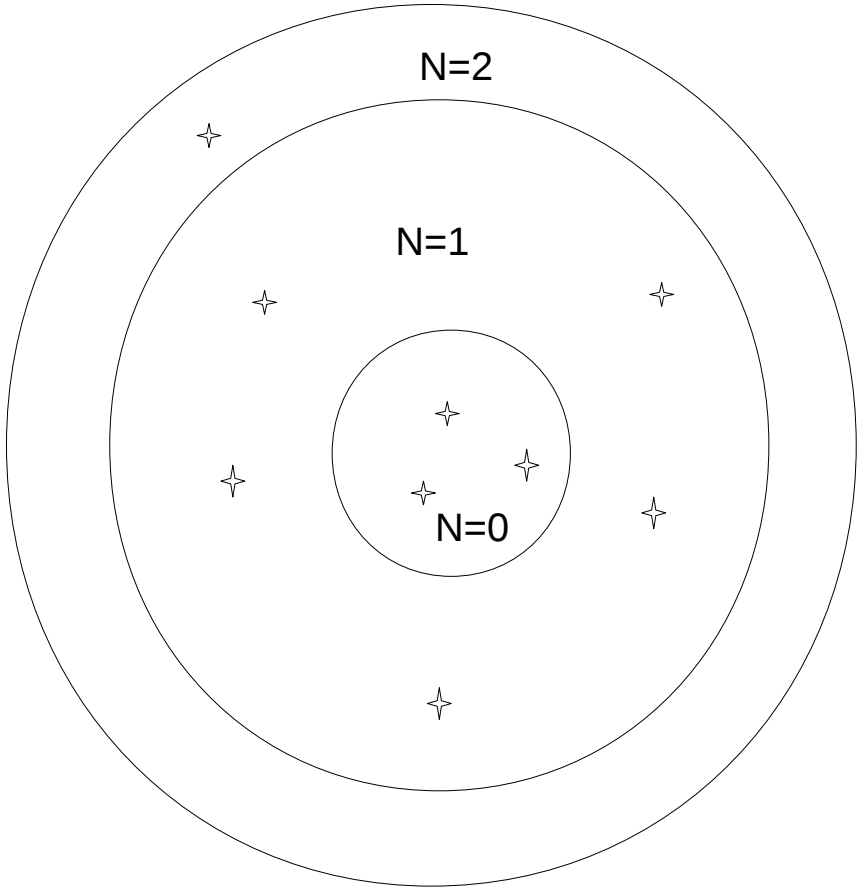
- Add $\mathcal{N} = 2$ Supersymmetry!
- Introduces 2x $\beta\gamma$ system and a $\eta\xi$-system
- $c_{ghosts} = c_{bc} + 2 \cdot c_{\beta\gamma} + c_{\eta\xi} = -26 + 2 \cdot 11 - 2 = -6$
- Each complex dimensions adds $c = 2 + 1$

$\rightarrow$ critical dimension 4! But two times... Still tachyonic, but can be projected out.

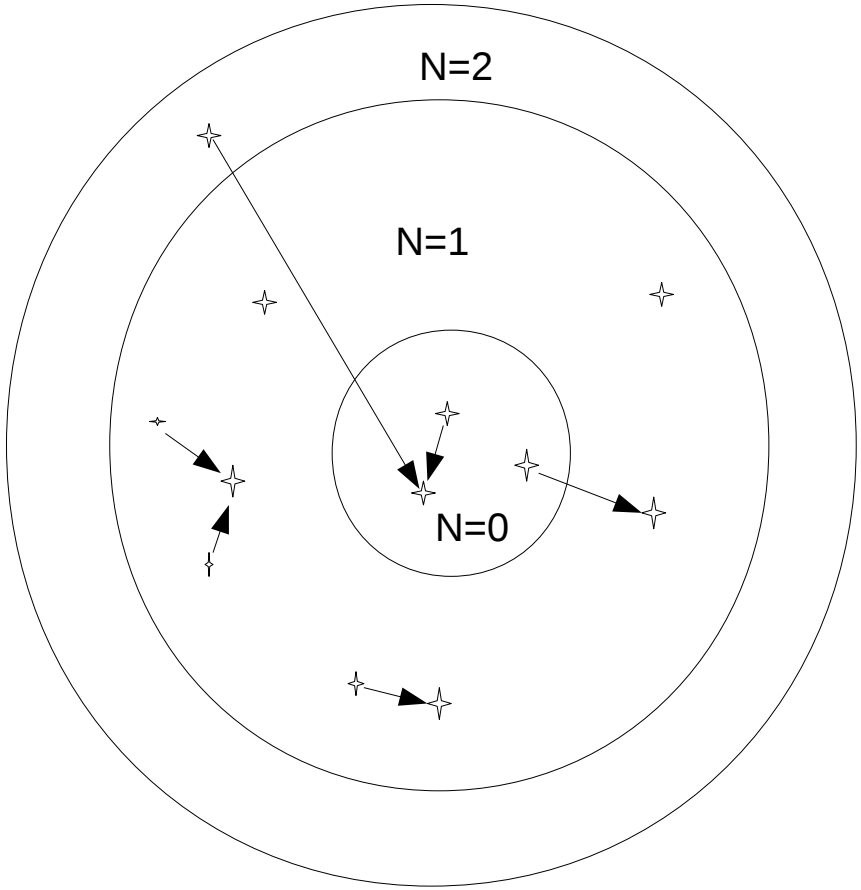
The forgotten Magic: The Berkovits embedding

- In 1993 Berkovits and Vafa showed that the bosonic string is part of the superstring moduli space. ("On the Uniqueness of String Theory ")
- 26D model $\in$ 10D model, this is crazy but works conformally!
- Adds spin 3/2 and -1/2 fermions instead of 1/2!(= spin shifted ghosts, real fermions!)
- $T = 26\,T_X + T_{bc} + T_{b'c'} + T_{\beta\gamma}$

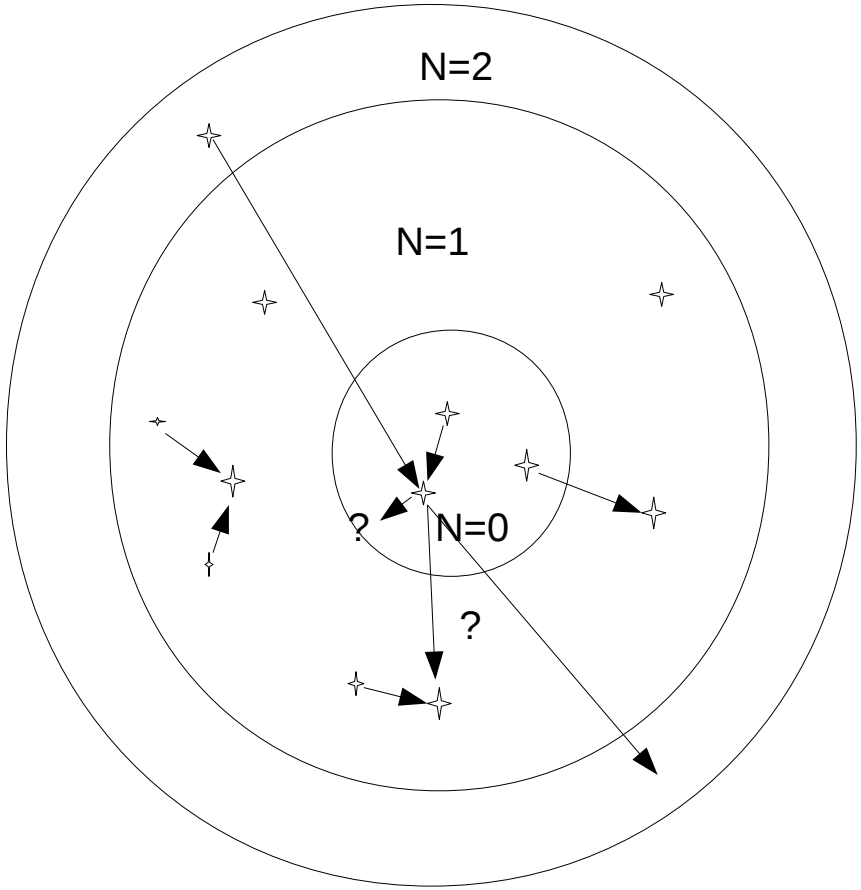
The Complete picture



The Complete picture



The Complete picture

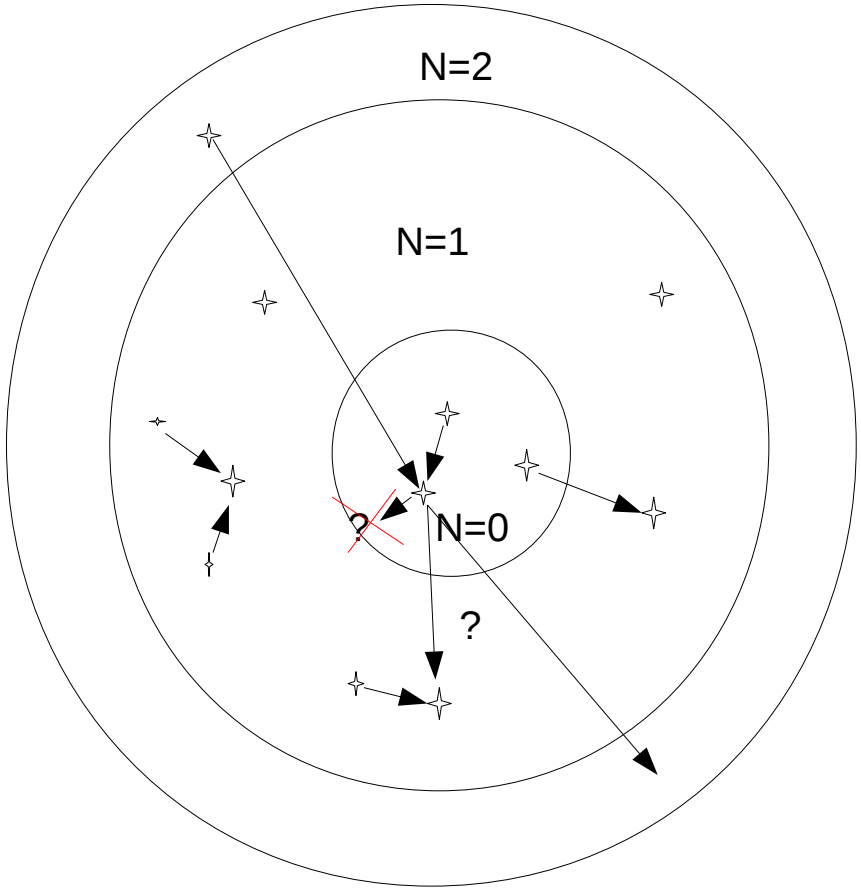


The Endpoint of the closed Bosonic Bulk Tachyon Condensation

How to determine which one is correct?

- Use Berkovits embedding + closed superstring field theory
- Subspace of the string field (matter ghost number -1) reproduces the bosonic result
- But fermionic directions destabilize the vacuum
- The Moeller Vacuum is false and only a boundary effect!

The Complete picture



Two possibilities

- The tachyon leads to a known D=10 $N = 1$ superstring theory$\rightarrow$would complete the picture but does not help at all... Wrong!
- The tachyon leads to a unknown D=4 $N = 2$ superstring theory, which could be the true vacuum of string theory!

Work in progress!

Unitarity Violation

- Normal in subsectors string theory
- More than one time $\rightarrow$ non-unitarity
- Tachyons change the number of times (and total dimensions) in the theory dynamically (e.g. $\mathcal{N} = 2$ tachyon leads to bosonic theory)

$\rightarrow$ Could unitarity violation explain existence of dS space?

Thank You