# Gauge Invariance and Tachyon Condensation in Open String Field Theory

Strings 2001
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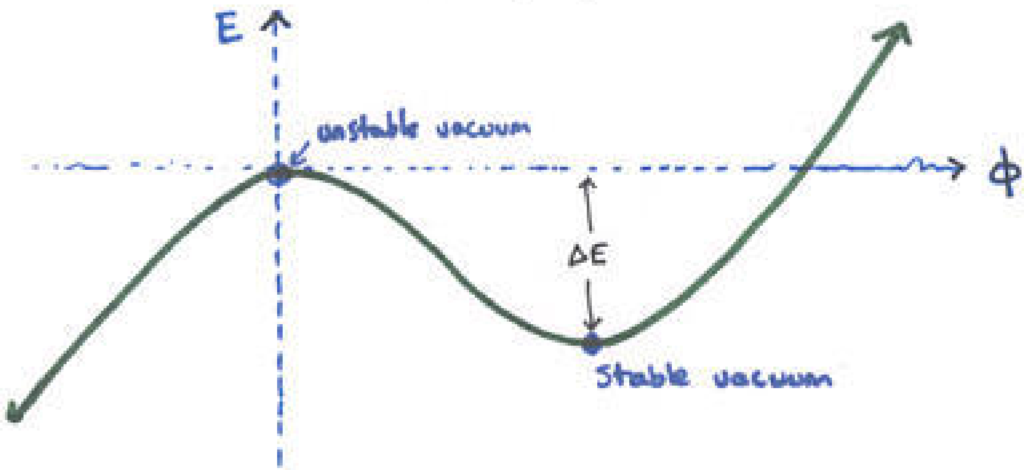
Based on work with I. Ellwood

# 1. Tachyon Condensation and String Field Theory

## Sen's conjecture:

Tachyon condensation in open bosonic string theory

- Corresponds to D25-brane decay
- Can be described by open SFT




## Predictions:

- $\Delta E = V T_{25}$
- Lower dimensional D-branes as solitons
- Closed string vacuum at bottom

## Witten's cubic string field theory:

String field

$$\Phi = \phi(p)|\hat{0};p\rangle + A_\mu(p)\alpha^\mu_{-1}|\hat{0};p\rangle + \cdots$$

Action

$$S = \frac{1}{2}\int \Phi \star Q\Phi + \frac{g}{3}\int \Phi \star \Phi \star \Phi$$

Invariant under

$$\delta\Phi = Q\Lambda + g\,(\Phi \star \Lambda - \Lambda \star \Phi)$$

Previous work:

i) Fixed Feynman-Siegel gauge $b_0\Phi = 0$

ii) Used level truncation (L, I)

(drop fields above level L and interactions above level I)

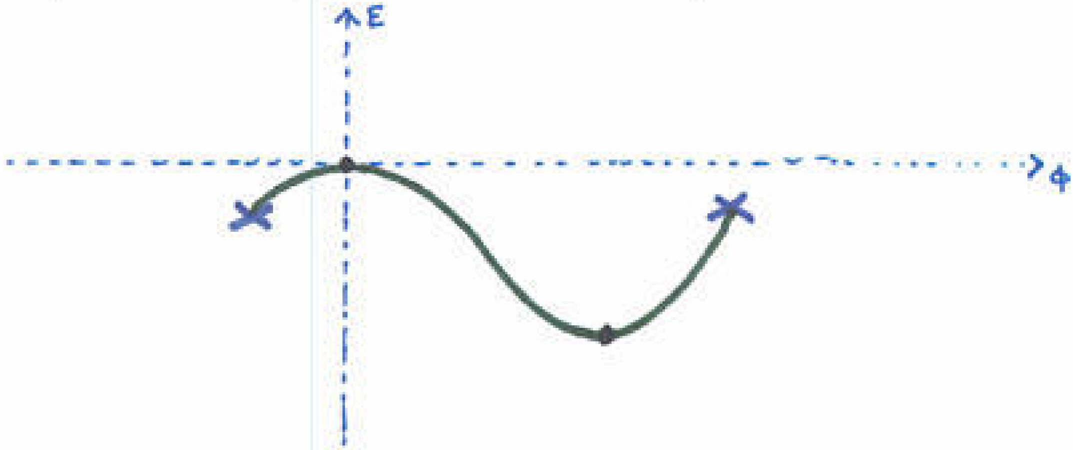
Zero-momentum scalar sector reproduces $T_{25}$ closely

| (L, I) | fields | $E/T_{25}$ | Authors |
|---|---|---|---|
| (2, 6) | 3 | -0.959 | Kostelecky-Samuel/Sen-Zwiebach |
| (4, 8) | 10 | -0.986 | Kostelecky-Samuel/Sen-Zwiebach |
| (10, 20) | 252 | -0.999 | Moeller-Taylor |

## Motivations for studying gauge invariance:

### Complication:

Tachyon effective potential has branch points




Are these physical?

### Main open problem:

Want to understand physics around stable vacuum.

Cubic string field theory gives new cubic action.

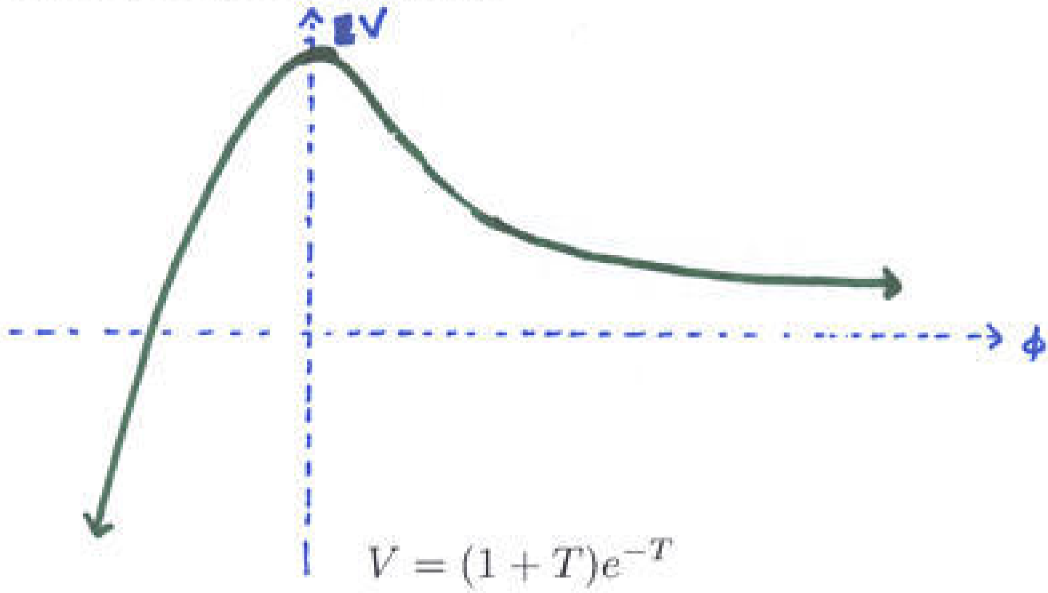
Open string excitations should be lifted.

Some evidence open strings removed from physical spectrum without vanishing of terms in action—but gauge invariance needed for clear understanding.

## Alternative approach: Boundary SFT (B-SFT)

Well-defined formalism for problems involving only $\phi, F_{\mu\nu}$

Tachyon potential very simple




$$V = (1 + T)e^{-T}$$

(Gerasimov-Shatashvili, Kutasov-Marino-Moore, Ghoshal-Sen)

- B-SFT believed related to cubic SFT by field redefinition
- No branch points in effective potential
- Physics in vacuum seems less accessible

## 2. Gauge Symmetry of Cubic SFT

Restrict attention to scalar fields at zero momentum

$$\Phi = \sum_i \phi^i |s_i^{(1)}\rangle$$

$$S = \sum_{i,j} d_{ij}\phi^i\phi^j + g\sum_{i,j,k} t_{ijk}\phi^i\phi^j\phi^k$$

Gauge parameter

$$\Lambda = \sum_a \mu^a |s_a^{(0)}\rangle$$

$$\delta\phi^i = D_{ia}\mu^a + gT_{ija}\phi^j\mu^a$$

- Action and gauge transforms computed to level (8, 16) without gauge fixing
- Gauge invariance exact to order $g^1$.
- Order $g^2$ invariance approximate, improved for larger $L$.

Example: Truncation at level 2

String field

$$\Phi = \phi|\hat{0}\rangle + B(\alpha_{-1}\cdot\alpha_{-1})|\hat{0}\rangle + \beta b_{-1}c_{-1}|\hat{0}\rangle + \eta b_{-2}c_0|\hat{0}\rangle + \cdots$$

Gauge parameter at level 2

$$\Lambda = \mu b_{-2}|\hat{0}\rangle + \cdots$$

Gauge transformations
(units: $g\kappa = 1, S = -\phi^2/2 + \phi^3 + \cdots$)

$$\delta\phi = \mu\left(-\frac{16}{9}\phi + \frac{2080}{243}B - \frac{464}{243}\beta + \frac{128}{81}\eta\right)$$
$$\delta B = \mu\left(\frac{1}{2} + \frac{40}{243}\phi - \frac{9296}{6561}B + \frac{1160}{6561}\beta - \frac{320}{2187}\eta\right)$$
$$\delta\beta = \mu\left(-3 - \frac{176}{243}\phi + \frac{22880}{6561}B - \frac{11248}{6561}\beta - \frac{6016}{6561}\eta\right)$$
$$\delta\eta = \mu\left(-1 - \frac{224}{81}\phi + \frac{29120}{2187}B + \frac{992}{6561}\beta + \frac{1792}{729}\eta\right)$$

Level (2, 6) action (Rastelli-Zwiebach) invariant to $g^1$.

## When is Feynman-Siegel gauge choice valid?

Near origin $\phi^i = 0$, transforms are constant vector fields

$$\delta\phi^i = D_{ia}\mu^a$$

FS gauge sets fields $\phi^q = 0$ for scalars with $c_0$.

Good gauge choice near origin.

Gauge choice breaks down when

$$\det M_{qa} = 0 \tag{1}$$

where

$$M_{qa} = D_{qa} + gT_{qja}\langle\phi^j\rangle.$$

In level truncated theory, $M_{qa}$ is finite size matrix.

Can study stability of (1) when level increases.

Illustrative example:

Keep only fields $\phi, \eta$

$$\delta\phi = -\frac{16}{9}\phi\mu + \frac{128}{81}\eta\mu$$
$$\delta\eta = -\mu - \frac{224}{81}\phi\mu + \frac{1792}{729}\eta\mu$$

Feynman-Siegel gauge sets $\eta = 0$.

Goes bad when

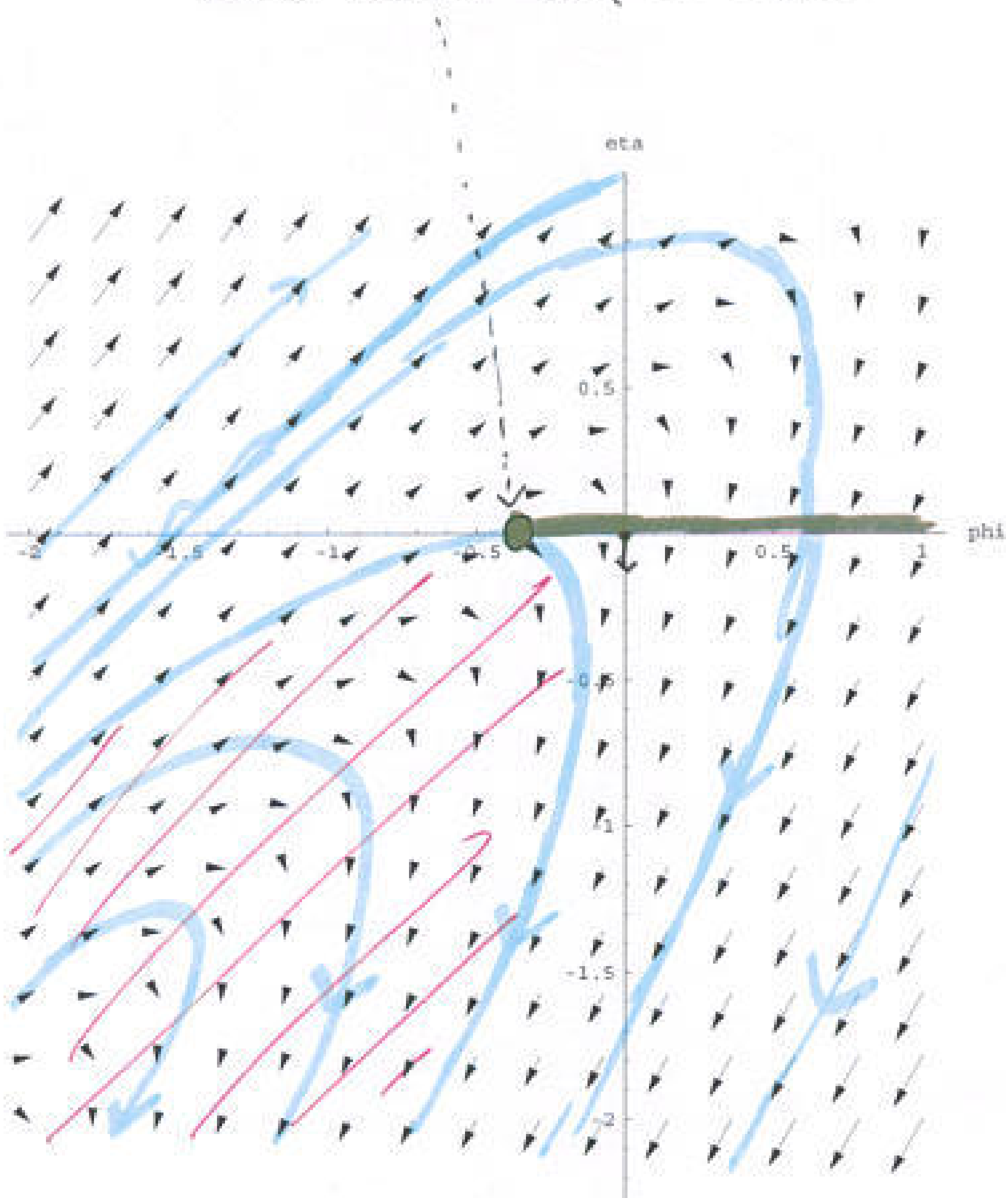
$$\eta = \delta\eta = 0 \quad \to \quad \phi = -81/224.$$

$\det M_{qa}$ computed on subspaces at various levels

- Closest vanishing locus to origin seems convergent under level truncation.
- Other local structure may start to converge
- Structure becomes very complex at higher levels

V3.ps

● FS gauge breaks down here ( $\phi \sim -0.36$ )
when all fields but $\phi, \eta$ are dropped



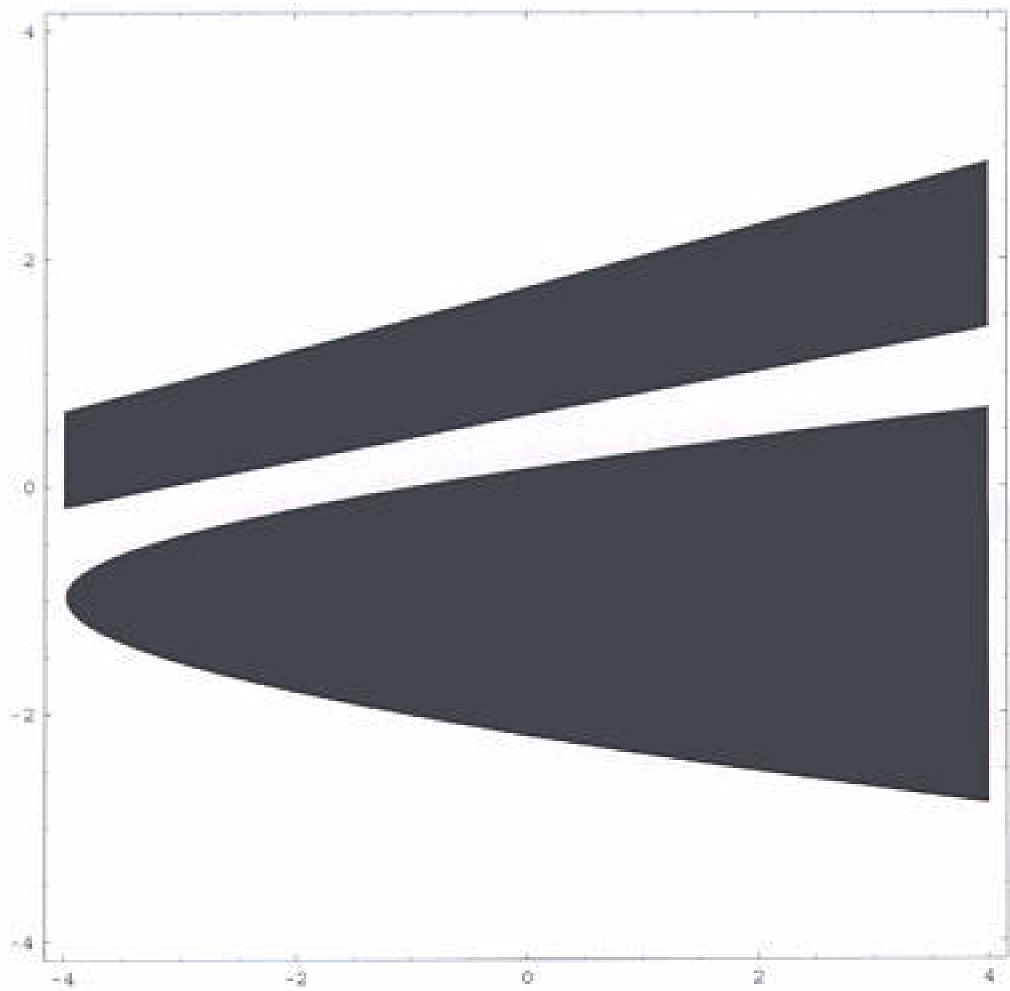
Fields in computation up to level (10, 20):

| Level | Total fields | Gauge DOF |
|---|---|---|
| 2 | 4 | 1 |
| 4 | 15 | 5 |
| 6 | 50 | 19 |
| 8 | 152 | 61 |
| 10 | 431 | 179 |

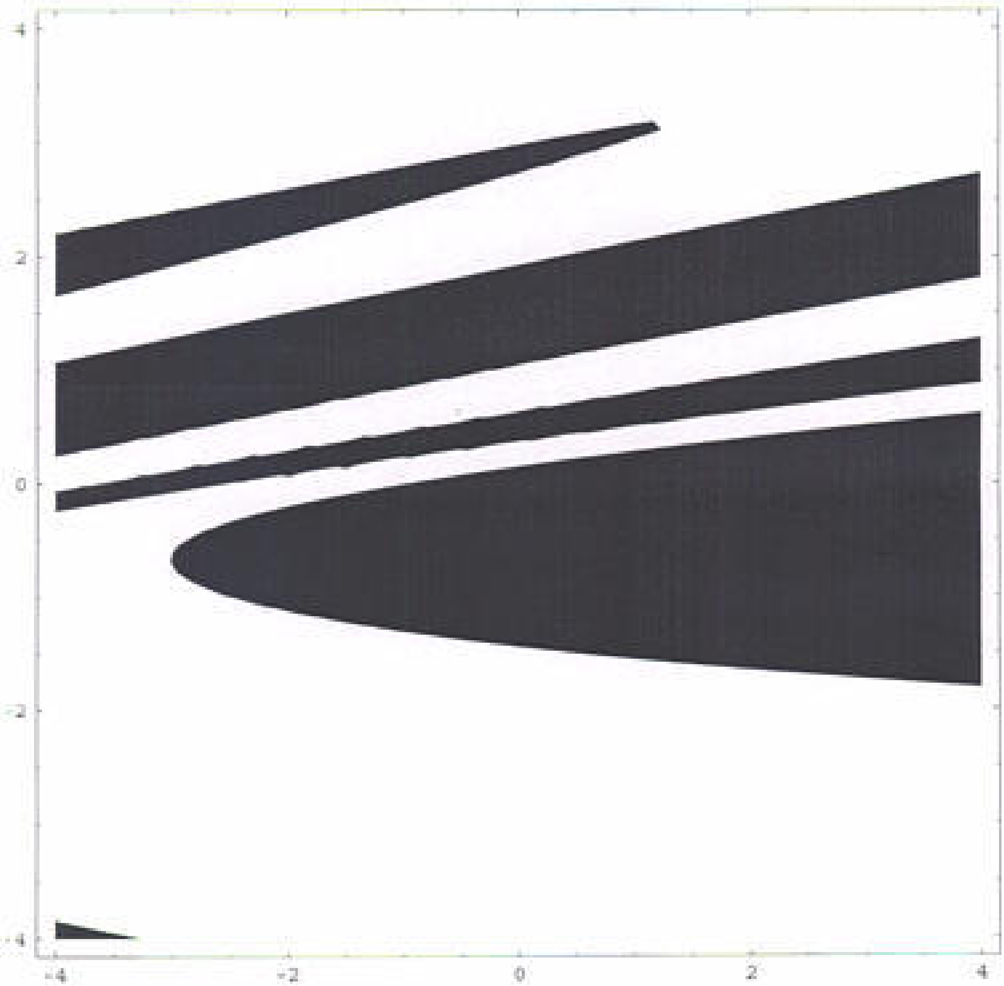
New results:

- Region of validity of Feynman-Siegel gauge has finite extent, seems stable under level truncation
- Branch points in tachyon effective potential correspond to intersections with boundary of FS gauge region.
- Gauge field EOM give extra constraints for FS gauge solution, satisfied approximately at finite level. Example: EOM for $\eta$ cancels to 99.7% at level 6. (Note: other constraints found by Hata-Shinohara, Schnabl, Zwiebach)

4-4-300

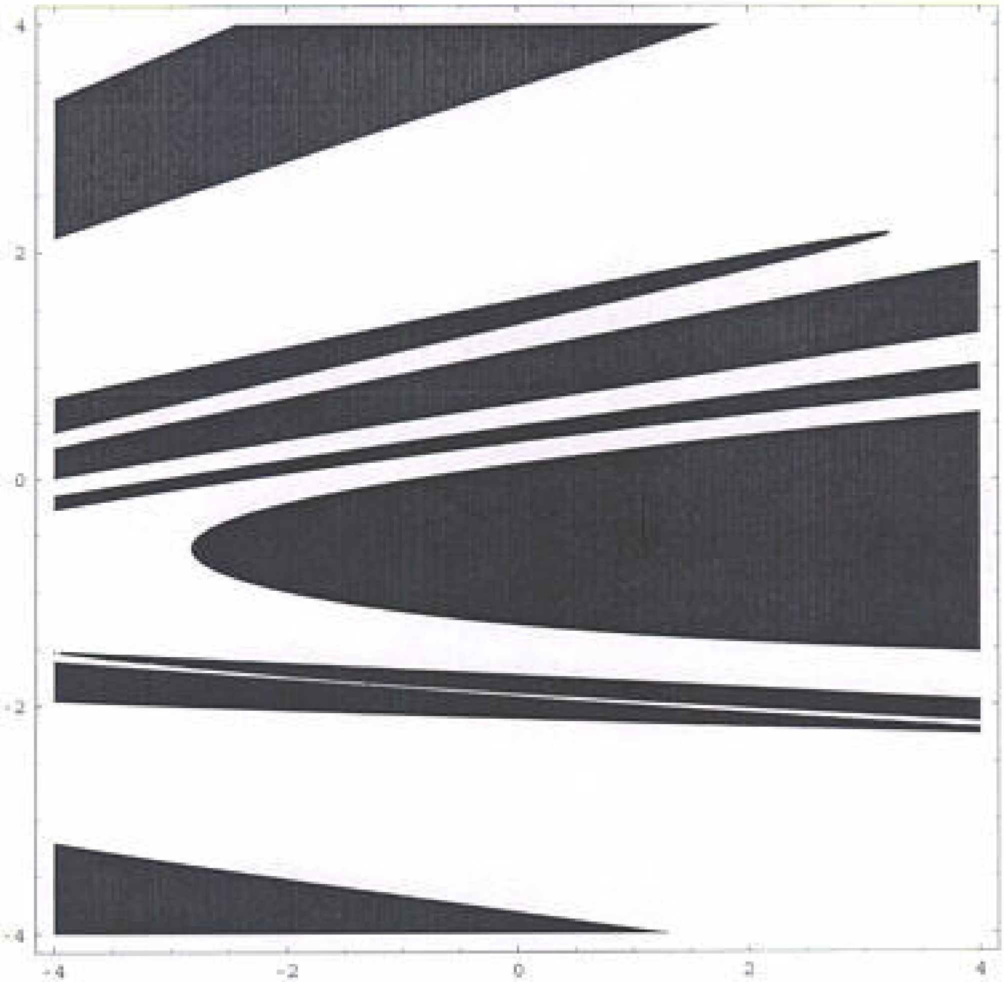



10b



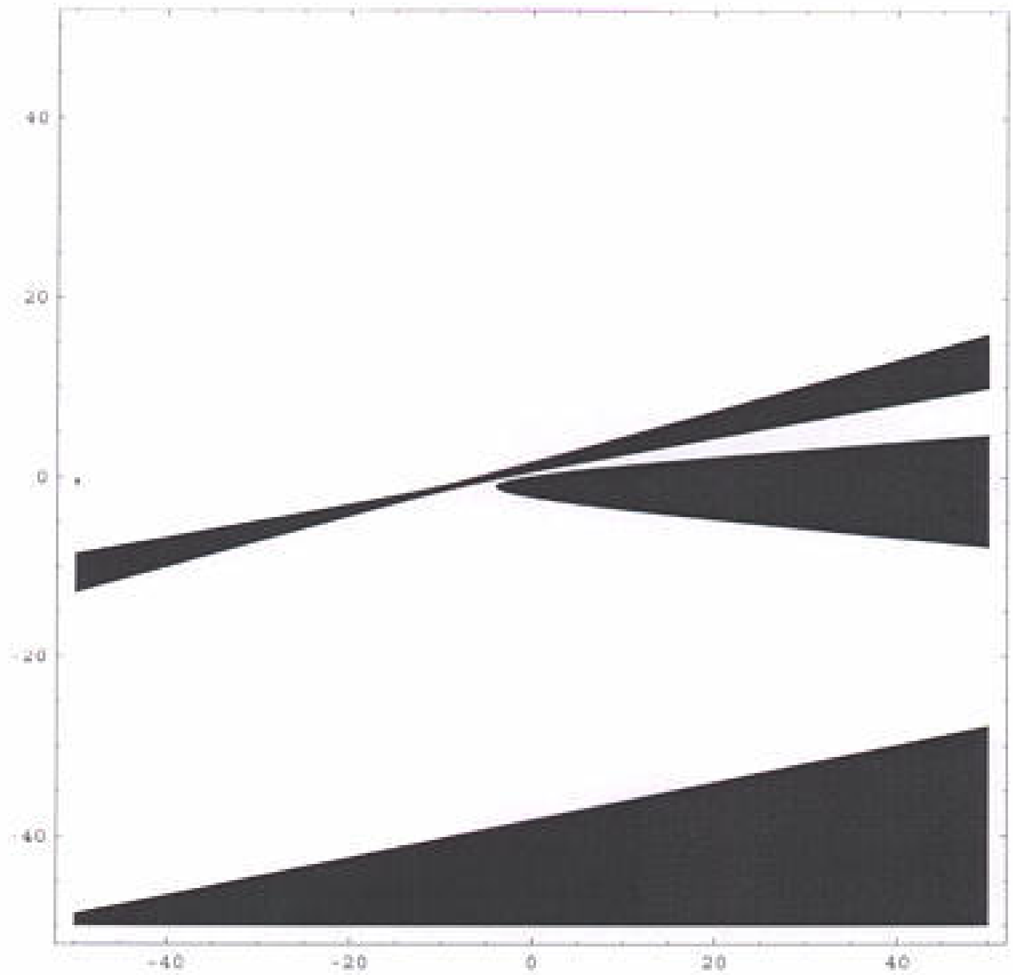

10c

8-4-400



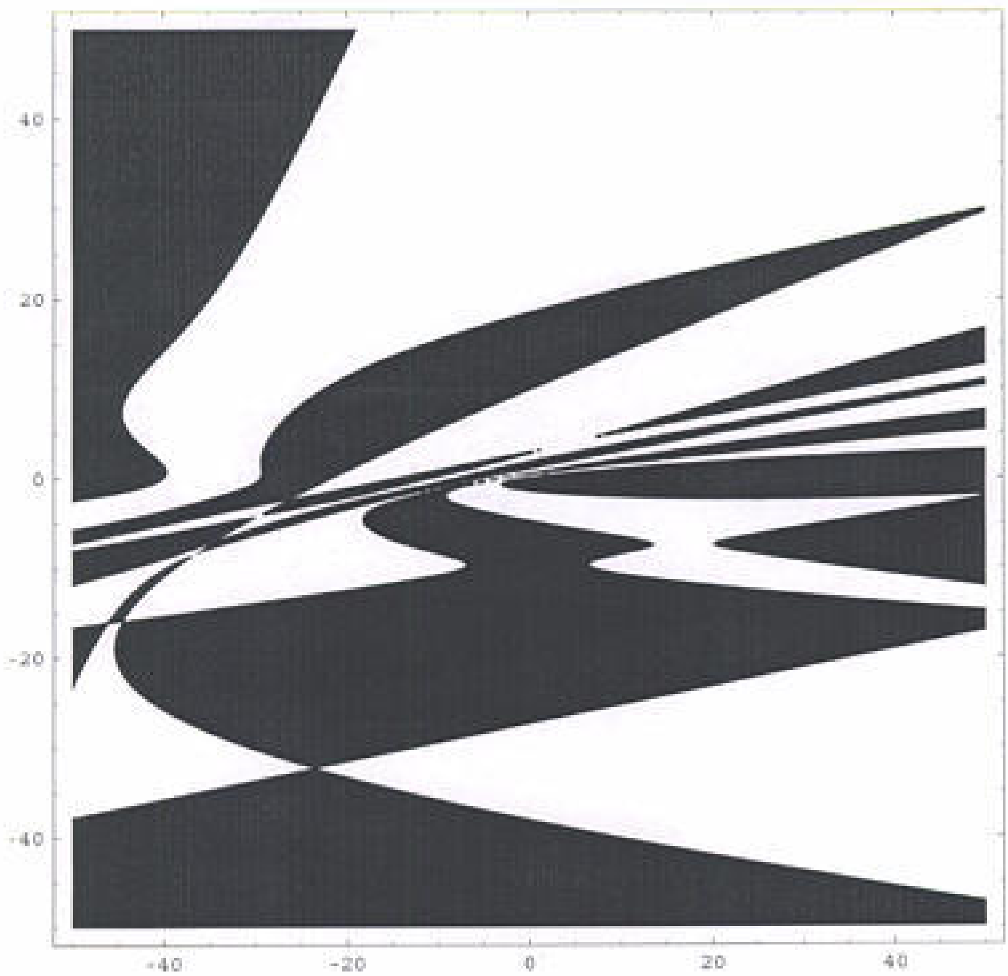

10d

4-50-600



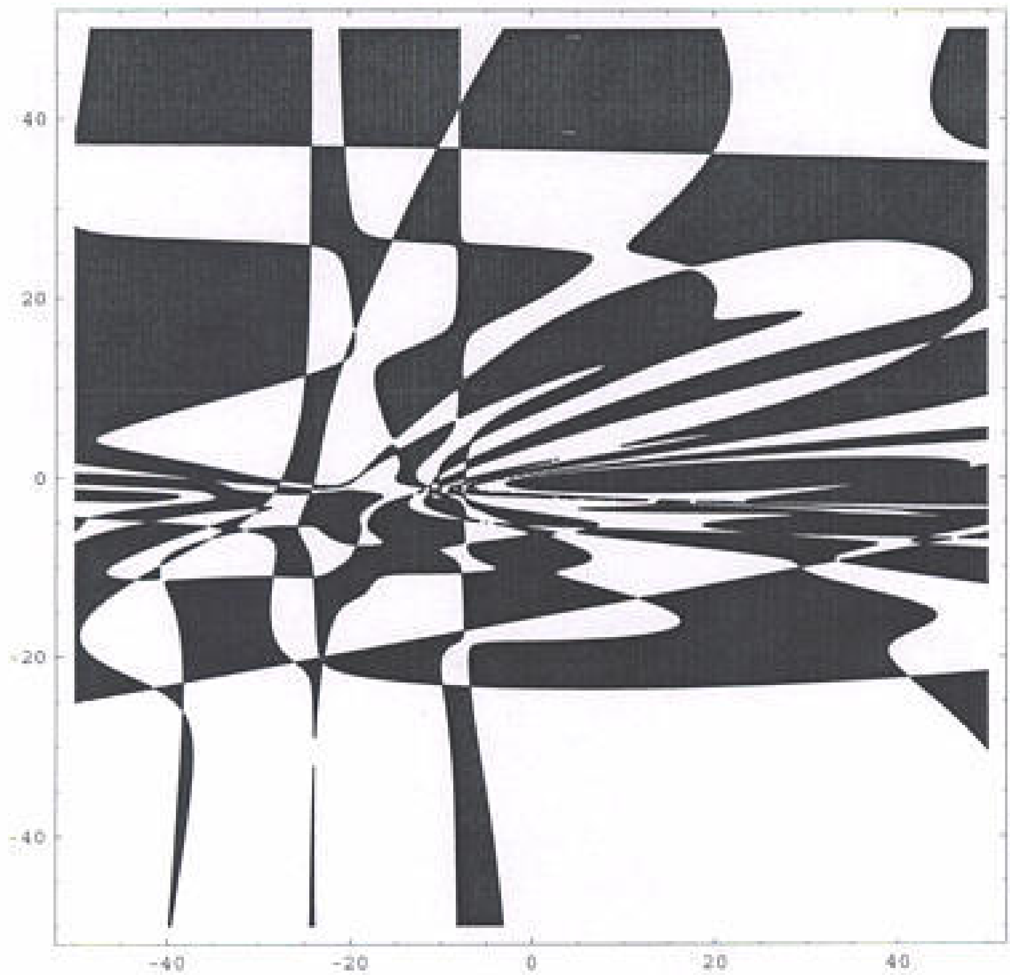

10e

6-50-400



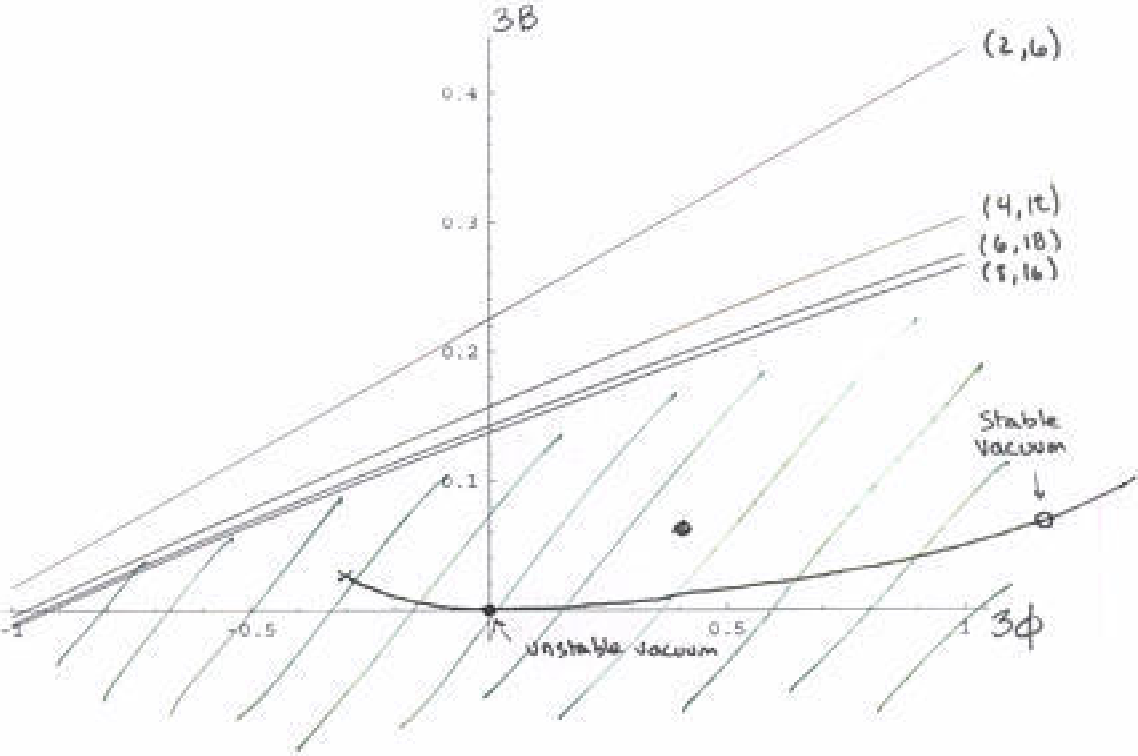

10f

8-50-600

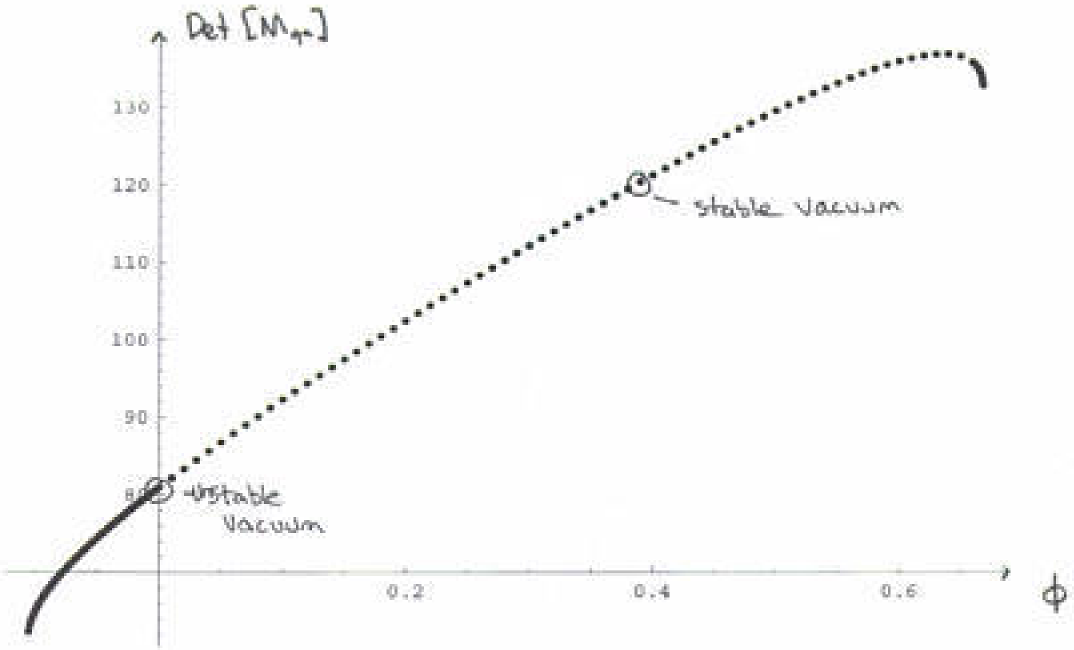



10g

local 28. ps




Successive approximations to boundary of region of FS gauge validity around origin determine4.ps




Det [$M_{qa}$] along tachon potential at level 4.

Question: can we find vacuum without gauge fixing?

Results not so good.

Level (2, 6):

Two solutions: $E/T_{25} =$ -0.880 (RZ), -1.078

Compare with FS gauge $E/T_{25} = -0.959$

Level (4, 12):

$E/T_{25} =$ -0.927047, -0.963483, -1.075

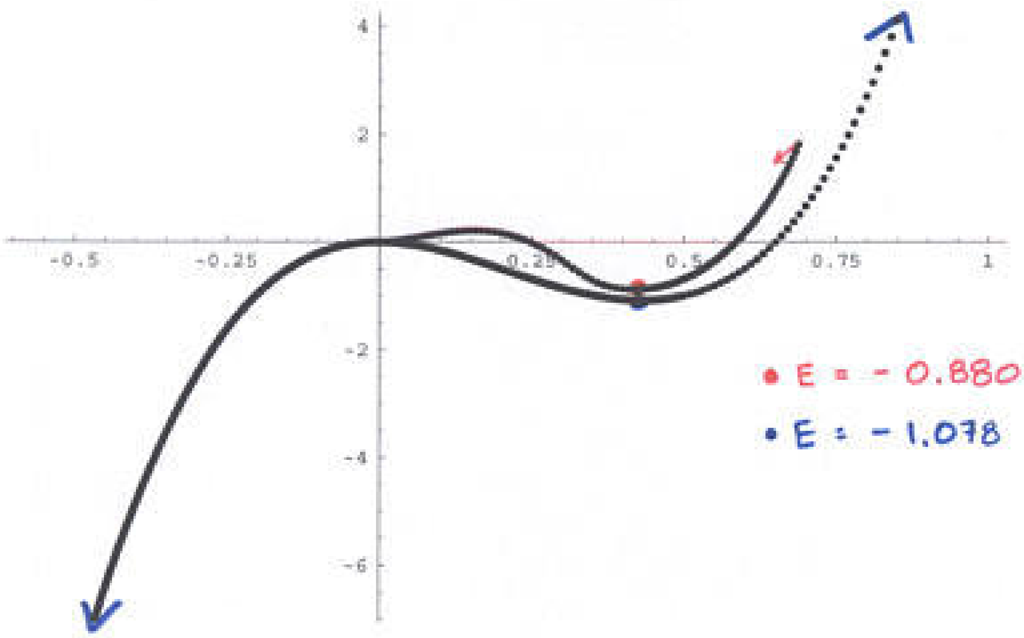
Compare with FS gauge $E/T_{25} = -0.988$

Problems:

No obvious choice of branch.

Converges poorly (if at all) compared to FS gauge.

unfixed - 2 . ps




Branches of tachyon effective potential
without gauge fixing (level 2)

How about other gauges?

At level 2 can fix $B = 0$ or $\beta = 0$ instead of $\eta = 0$ (or any linear combination)

$B = 0$: $E/T_{25} =$ -0.901

$\beta = 0$: $E/T_{25} =$ -0.893

$\eta = 0$: $E/T_{25} =$ -0.959

At level 4 many gauge choices.

Example: setting $\phi_{12} = 0$ instead of $\phi_{15} = 0$, using FS gauge otherwise gives

Level 4: -0.9985 (vs. 0.9878 FS gauge)
Level 6: -1.0028 (vs. 0.9952 FS gauge)
Level 8: -1.0038 (vs. 0.9978 FS gauge)

Note that level approximation worse at level 8, approach to 1 is not monotonic.

Conclusion: FS gauge is not too much better or worse than other linear gauge choices, but has virtue of monotonicity.

Are there better (possibly nonlinear) gauges?

## Summary of Results

- Feynman-Siegel gauge not globally valid
- Boundary of FS validity region stable under level truncation
- Branch points in effective tachyon potential are gauge artifacts
- Hard to compute without gauge fixing
- Other linear gauges seem similar to FS gauge; some better, some worse
- FS gauge special because of monotonic approach to vacuum energy

## Further Directions/Work in Progress

- Direct connection with B-SFT through field redefinitions

- Understand gauge invariance in (meta)stable vacuum, connection with $m^2 A_\mu A^\mu$ term

- Use gauge invariance to control spectrum calculation at bottom of hill