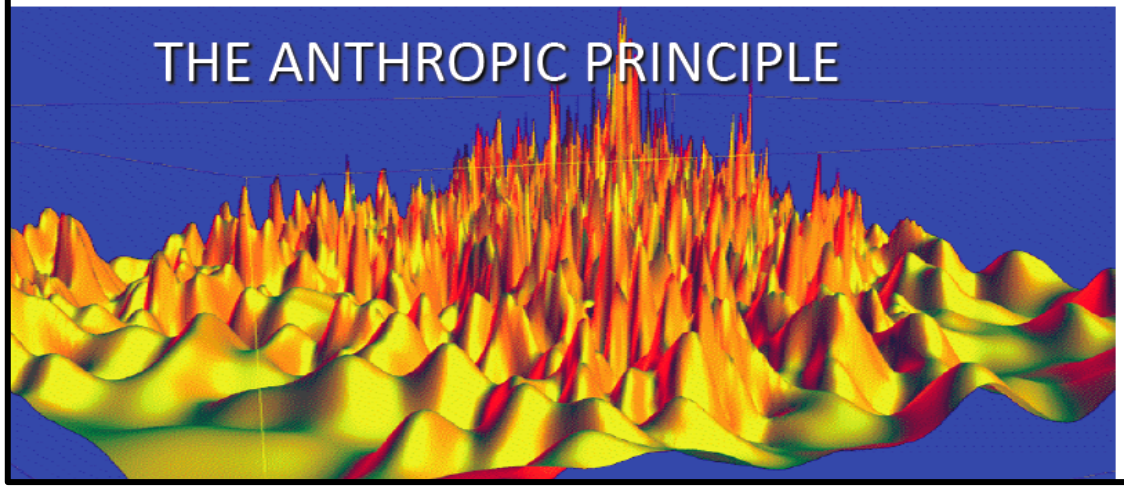
String theory should give a unique vacuum?

Are All the Parameters and Laws That Characterize the Physical Universe Calculable (in Principle) or Are Some Determined By Historical or Quantum Mechanical Accident ?

THE LANDSCAPE



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Slide by D.Gross, 2005, Madrid

A Landscape in Boundary String Field Theory

Koji Hashimoto (Osaka / RIKEN)

w/ Masaki Murata (Czech)

arXiv:1211.5949 (published in PTEP)

String Landscape is richer than expected

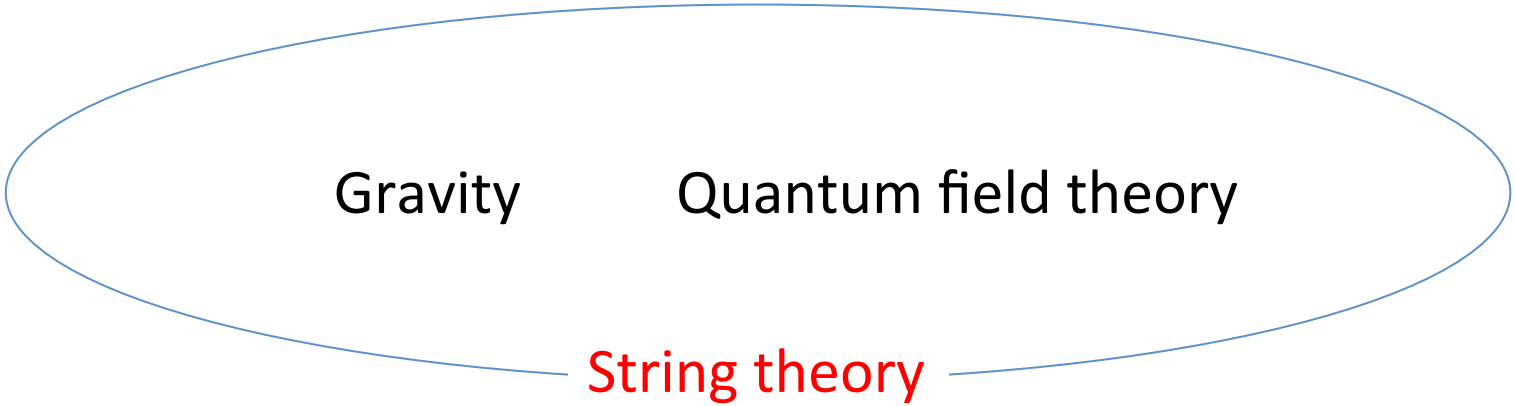
Condensation of massive stringy states

→ Many new nonperturbative string vacua

Road map

1. Ultimate question: unique vacuum? 2 pages
2. String field theories for the answer 3 pages
3. Massive states and boundary SFT 3 pages
4. Many new vacua: interpretation? 3 pages

Ultimate question : unique vacuum?

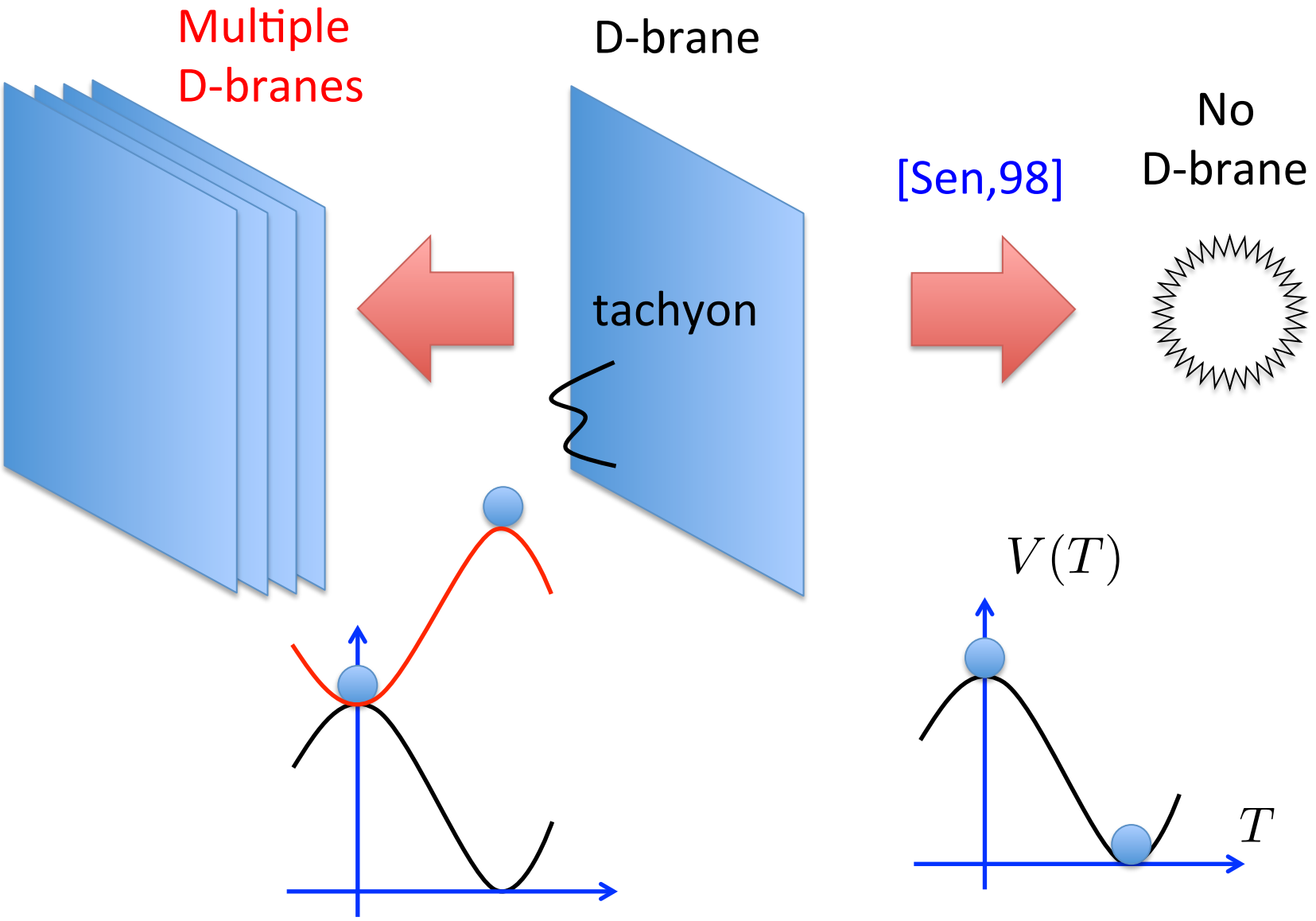


String theory action
= Fields: Massless + infinite number of massive modes
Interactions: gauge invariance

(Quantum) calculations

Non-perturbative Vacua

At least you need to describe…



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String field theories for the answer

Among non-perturbative approaches…

1. Low energy supergravity + non-perturbative effect.

   KKLT, Moduli stabilization. KKLMMT, inflation.

   Are vacua truly non-perturbative?

2. Matrix models.

   IIB matrix model, BFSS Matrix Theory, Matrix string

   How to solve them? Gravitons? AdS/CFT?

3. String field theories (“SFT”).

   CSFT (cubic SFT, Witten) , HIKKO’s SFT. Open/closed.

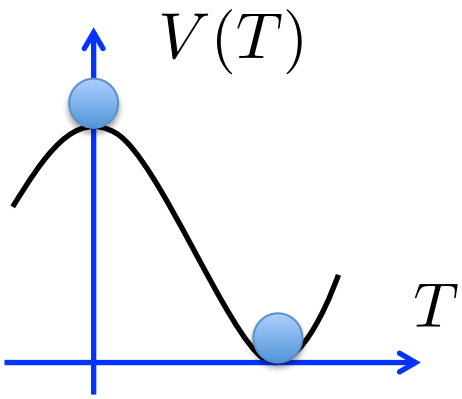
   BSFT. (boundary/background-independent SFT)

   Non-perturbative, intuitive, straightforward.

Importance of SFT : Proof of Sen's conjecture

Sen's conjecture [Sen 98]:

Open-string tachyon condensation on unstable D-branes = Disappearance of the D-branes

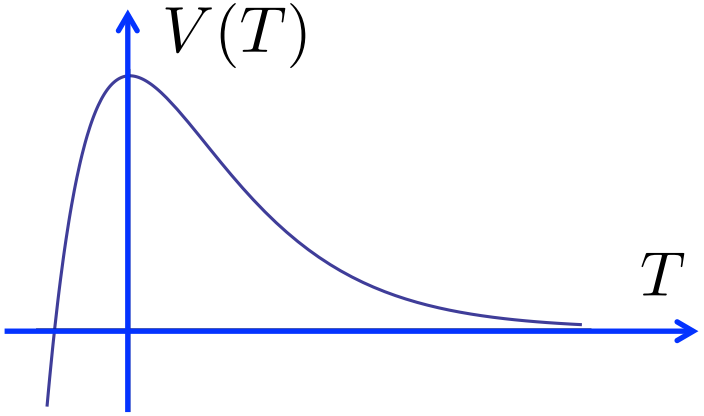


Proof: both by BSFT and CSFT.

[Gerasimov Shatashvili 00]
[Kutasov Marino Moore 00]
[Sen Zwiebach 99] [Moeller Taylor 00]
[Schnabl 07]

BSFT tachyon potential

$$U = T_{25} V_{26}\, e^{-T}(T+1)$$



Importance: Touchstone for any non-perturbative formulation of string theory.

Virtue of the BSFT against CSFT

Consistent truncation system. [Kutasov Marino Moore 00]

$$U = T_{25} V_{26}\, e^{-T} (T+1)$$

Putting other fields to zero is a consistent solution.

Cf) CSFT: Intrinsically infinite DoFs, level truncation needed.

$$-\frac{1}{2}t^2 + \frac{3^3\sqrt{3}}{2^6}t^3 - \frac{1}{2}u^2 + \frac{1}{2}v^2 + \frac{11\cdot 3\sqrt{3}}{2^6}t^2 u - \frac{5\cdot 3\sqrt{39}}{2^6}t^2 v + \frac{19}{2^6\sqrt{3}}t u^2 + \frac{7\cdot 83}{2^6\cdot 3\sqrt{3}}t v^2 - \frac{11\cdot 5\sqrt{1}}{2^5\cdot 3\sqrt{}}$$

Field-theoretically intuitive.

DBI action is a part of BSFT. $S = \int d^{26}x \sqrt{-\det(\eta_{\mu\nu} + F_{\mu\nu})}$

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Our BSFT potential

Fields (Variables) $T, u_k^\mu \ (k = 1, 2, 3, \cdots, \ \mu = 0, \cdots, 25)$

Tachyons and massive fields

The BSFT potential [Li Witten 93] [Murata KH 12]

$$U = T_{25} V_{26} \ e^{-T} \left(T + 1 - \sum_{\mu=0}^{25} \sum_{k=1}^{\infty} \beta_k^\mu \left(\frac{1}{k + u_k^\mu} - \frac{1}{k} \right) \right) \prod_{k=1}^{\infty} \prod_{\mu=0}^{25} e^{k^{-1} u_k^\mu} (1 + k^{-1} u_k^\mu)^{-1}$$

$$\beta_1^\mu = \frac{1}{2} u_2^\mu - u_1^\mu, \quad \beta_{k \geq 2}^\mu = \frac{1}{2} k \left(u_{k+1}^\mu - u_{k-1}^\mu \right) - u_k^\mu$$

With vanishing massive fields, it reproduces

$$U = T_{25} V_{26} \ e^{-T} (T + 1)$$

BSFT = set of all 2d theories

[Witten 92] [Shatashvili 93]
[Kutasov Marino Moore 00]
[Marino 01] [Ghoshal 01]
[Niarchos Prezas 01]

$$S_{\rm BSFT} = Z_{\rm 2d}$$

$$Z_{\rm 2d} \sim \int \mathcal{D}X \ \exp\left[- \int d^2\sigma \ \eta^{ab} \partial_a X^\mu \partial_b X^\nu - S_{\rm int} \right]$$

The interaction includes all 2d nonlinear boundary couplings

Ex) The DBI action can be calculated by

$$S_{\rm int} \sim \oint d\tau \ \partial_\tau X^\mu A_\mu[X] = -\frac{1}{2} \oint d\tau \ \partial_\tau X^\mu F_{\mu\nu} X^\nu$$

Solutions of Eq. of motion of BSFT
= Conformal fixed points on worldsheet
= Consistent background in string theory

Exact treatment of Massive stringy excitations

Free 2d theory: exactly calculable, consistent truncation

$$O = c(\theta)V(\theta)\,, \quad V(\theta) = \frac{a}{2\pi} + \frac{1}{4\pi\alpha'} \,:X_\mu(\theta)\int_0^{2\pi} d\theta'\, u^{\mu\nu}(\theta-\theta')X_\nu(\theta'):$$

Non-local mode expansion $u_k^{\mu\nu} = u_{-k}^{\nu\mu} = \int_0^{2\pi} d\theta\, u^{\mu\nu}(\theta)e^{-ik\theta}$

$$\frac{\partial}{\partial u_k^{\mu\nu}} \ln Z = -\frac{1}{8\pi^2\alpha'}\int_0^{2\pi} d\theta \int_0^{2\pi} d\theta' e^{ik(\theta-\theta')} \langle :X_\mu(\theta)X_\nu(\theta'):\rangle_\lambda = \frac{1}{2}\,A_{k,\nu\mu}$$

$$\Downarrow \qquad A_{0,\mu\nu} = -(u_0^{-1})_{\mu\nu}\,, \quad A_{k,\mu\nu} = \frac{1}{|k|}\eta_{\mu\nu} - \left(\frac{1}{|k|\eta + u_k}\right)_{\mu\nu} \quad \text{for} \quad k \neq 0$$

$$Z = \mathcal{N}\det(u_0)^{-1/2}e^{-a}\prod_{k=1}^{\infty} e^{k^{-1}\mathrm{tr}(\eta\cdot u_k)}\det(1+k^{-1}\eta\cdot u_k)^{-1}$$

$$\Downarrow$$

$$S_{\mathrm{BSFT}} = \left(\beta_i[\lambda]\frac{\partial}{\partial\lambda_i} + 1\right) Z$$

$$= T_{25}V_{26}\; e^{-T}\left(T + 1 - \sum_{\mu=0}^{25}\sum_{k=1}^{\infty}\beta_k^\mu\left(\frac{1}{k+u_k^\mu} - \frac{1}{k}\right)\right)\prod_{k=1}^{\infty}\prod_{\mu=0}^{25} e^{k^{-1}u_k^\mu}(1+k^{-1}u_k^\mu)^{-1}$$

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Solving the potential, easy

Our BSFT potential $\beta_1^\mu = \frac{1}{2}u_2^\mu - u_1^\mu\,, \quad \beta_{k\geq 2}^\mu = \frac{1}{2}k\left(u_{k+1}^\mu - u_{k-1}^\mu\right) - u_k^\mu$

$$U = T_{25}V_{26}\; e^{-T}\left(T+1-\sum_{\mu=0}^{25}\sum_{k=1}^{\infty}\beta_k^\mu\left(\frac{1}{k+u_k^\mu}-\frac{1}{k}\right)\right)\prod_{k=1}^{\infty}\prod_{\mu=0}^{25}e^{k^{-1}u_k^\mu}(1+k^{-1}u_k^\mu)^{-1}$$

First, solve the tachyon equation of motion $\dfrac{\partial U}{\partial T} = 0$

⇨ Sol.1 $T = \infty$ with u_k^μ arbitrary (Sen's vacuum)

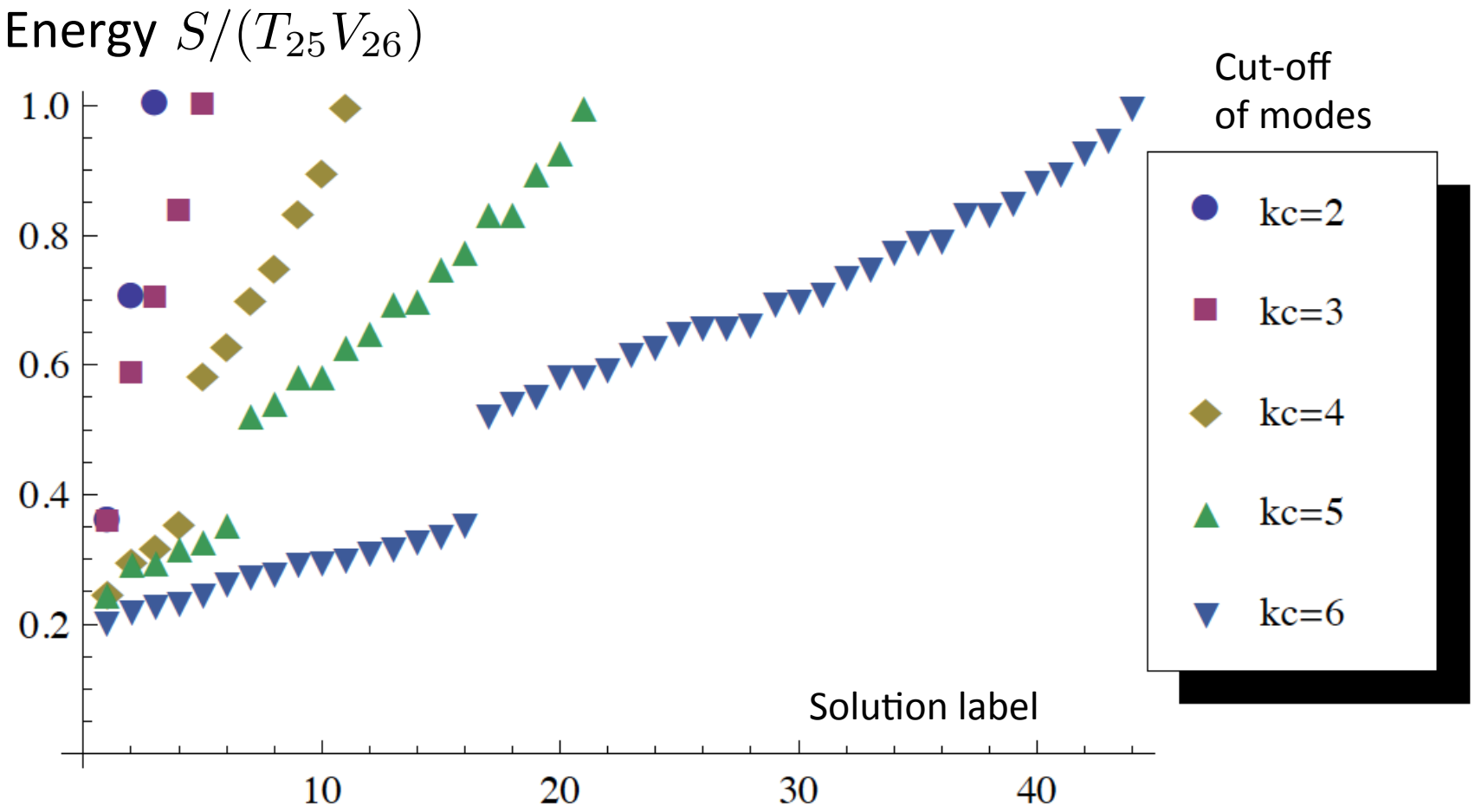
Sol.2 $$T = \sum_{\mu=0}^{25}\sum_{k=1}^{\infty}\beta_k^\mu\left(\frac{1}{k+u_k^\mu}-\frac{1}{k}\right)$$ (New vacua)

$$U = T_{25}V_{26}\; e^{-\sum_{\mu=0}^{25} f(u^\mu)}$$

$$f(u) = \sum_{k=1}^{\infty}\left(\beta_k\left(\frac{1}{k+u_k}-\frac{1}{k}\right) - k^{-1}u_k + \log(1+k^{-1}u_k)\right)$$

Extremizaion of *f(u)* gives new nonperturbative vacua

Strange behavior of the numerical results



- Range : between the D-brane tension and zero energy
- Uniform distribution

Interpreting them as closed strings?!

Are they… multiple D-branes?

--- In bosonic string theory, there is no D-brane charge,
so D-brane bound states do not necessarily give integers.

Are they… closed string excitations at the no-D-brane vacuum?

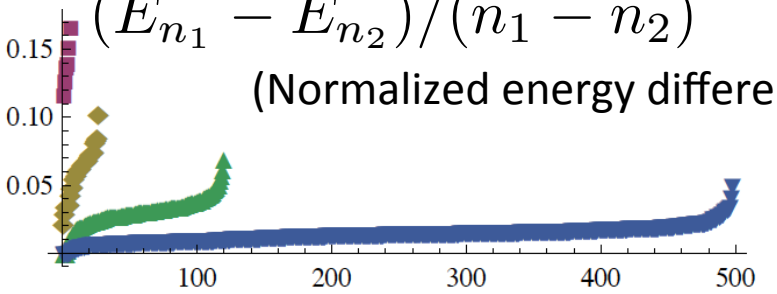
Evidence 1. Closed string vertex insertion
~ Nonlocal boundary interactions

[Baumgartle Sachs Schatashvili 04]

Evidence 2. Almost uniform distribution of energy values.

$(E_{n_1} - E_{n_2})/(n_1 - n_2)$

(Normalized energy differences)



Evidence 3. Huge degeneracy, looks like a closed string spectrum.

Solution with different μ combination.
Uniformity of f giving, say, $f_2 = 2 f_1$ etc.

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