Tachyon Condensation and Open String Field theory

Taejin Lee *

Department of Physics, Kangwon National University, Chuncheon 200-701, Korea

(March 27, 2022)

Abstract

We perform canonical quantization of the open string on a unstable D-brane in the background of the tachyon condensation. Evaluating the Polyakov path-integral on a strip, we obtain the field theoretical propagator in the open string theory. As the condensation occurs the string field theory is continuously deformed. At the infrared fixed point of the condensation, the open string field on the unstable D-brane transmutes to that on the lower dimensional D-brane with the correct D-brane tension.

*E-mail: taejin@cc.kangwon.ac.kr
I. INTRODUCTION

The tachyon condensation is a noble phenomenon in string theory, which determines the ultimate fates of the unstable D-branes and the $D$-$\bar{D}$-brane pairs. The unstable systems in string theory are expected to reduce to the stable lower dimensional D-brane systems or disappear into the vacuum, leaving only the closed string spectrum behind. Since the celebrated Sen’s conjecture [1] on the tachyon condensation many important aspects of this noble phenomena have been explored by numerous authors. Since the tachyon condensation is the off-shell phenomenon, the theoretical framework to deal with it should be the second quantized string theory. The main tools to discuss the tachyon condensation are the open string field theory with the level truncation [2] and the boundary string field theory [3,4]. The former one, which is based on the Witten’s cubic open string field theory [5], has been a useful practical tool to describe the decay of the unstable D-branes to the bosonic string vacuum. The latter one, which is based on the background independent string field theory, has been useful to obtain the effective tachyon potential. These two approaches are considered to be complementary to each other.

In a recent paper [6] we discuss the tachyon condensation in a single D-brane, using the boundary state formulation [7,8], which is closely related to the latter one. As we point out, the boundary state formulation contains the boundary string field theory, since the normalization factor of the boundary state corresponds to the disk partition function, which is the main ingredient of the latter approach. Moreover, it provides an explicit form of the quantum state of the system in terms of the closed string wavefunction. Thus, we may find a direct connection between the boundary state formulation and the former approach based on the string field theory if we appropriately utilize the open-closed string duality. It suggests that the succinct boundary state formulation of the tachyon condensation may be transcribed into the open string field theory. The purpose of this paper is to construct the open string field theory in the background of the tachyon condensation and to show that the descent relations among the D-branes is also well described in the framework of the open
string field theory. To this end we perform canonical quantization \cite{9} of the open string on a unstable D-brane in the background of the tachyon condensation. Then we evaluate the Polyakov string path-integral on a strip to obtain the field theoretical propagator of the open string theory in the background of the tachyon condensation. At the infrared fixed point of the condensation, the open string field on the unstable D-brane transmutes to that on the lower dimensional D-brane with the correction D-brane tension.

II. CANONICAL QUANTIZATION

It is well known that the field theoretical string propagator is obtained from the first quantized string theory, by evaluating the Polyakov path-integral over a strip, which is the world-sheet of the open string in this case. Following the same steps, we will construct the field theoretical open string propagator in the background of the tachyon condensation. To this end we perform canonical quantization of the open string attached on D-brane in the tachyon background. Then integration over the proper time yields the string propagator, therefore the kinetic part of the second quantized string theory. As we vary the parameter of the tachyon profile, the field theoretical action for the open string on a D-brane is continuously deformed and eventually reduced to that on a lower dimensional D-brane. For the sake of simplicity we consider the bosonic string on a single D-brane. Extension to more general cases is straightforward.

The action for the open string in the background of the tachyon condensation is given as \cite{10}

\[
S = S_M + S_T = -\frac{1}{4\pi\alpha'} \int_M d\tau d\sigma \sqrt{-\hbar h^{\alpha\beta}} g_{\mu\nu} \partial_\alpha X^\mu \partial_\beta X^\nu + \int_{\partial M} d\sigma N T(X) \tag{1}
\]

where we consider a simple tachyon profile, \( T(X) = u_{ij} X^i X^j \). Here \( N \) is an einbein on the world-line of the end points of the open string and its relation to the world-sheet metric is given by
\[ \sqrt{-\mathcal{h}} \mathcal{h}^{\alpha\beta} = \frac{1}{N} \begin{pmatrix} -1 & 0 \\ 0 & N^2 \end{pmatrix}. \] (2)

That is, \( N \) is the lapse function of the world-sheet metric. The string action is manifestly invariant under the reparametrization. We may fix this reparametrization invariance by choosing the proper-time gauge, \( \frac{dN}{d\tau} = 0 \), equivalently \( N = T \), constant. Hereafter we confine our discussion to the proper-time gauge. The string propagator is defined as a Polyakov path-integral over a strip [11]

\[ G[X_f; X_i] = \int D[N] D[X] \exp (i S_M + i S_T) \] (3)

where the path integral is subject to the boundary condition \( X^\mu(\tau_f, \sigma) = X_f^\mu(\sigma), X^\mu(\tau_i, \sigma) = X_i^\mu(\sigma) \).

In order to understand the structure of the open string propagator on a \( D \)-brane, let us first consider a flat \( D \)-brane where \( S_T = 0 \). Introducing the canonical momenta \( P_\mu \), we find that the propagator is written as

\[ G[X_f; X_i] = \int_0^\infty \! dt \int D[X, P] e^{i \int_0^t (\int P_\mu \dot{X}^\mu - H) \! d\sigma} d\tau. \] (4)

If we expand the canonical variables in terms of normal modes \( X^\mu(\sigma) = \sum_n X_n^\mu e^{in\sigma}; P_\mu(\sigma) = \sum_n P_n^\mu e^{-in\sigma} \), we find that the Hamiltonian is given as

\[ H = \frac{1}{2} \sum_n g_{\mu\nu} \left( (2\pi\alpha') P_n^\mu P_{-n}^\nu + \frac{n^2}{(2\pi\alpha')} X_n^\mu X_{-n}^\nu \right). \] (5)

For the open string on a \( Dp \)-brane in \( d \) dimensions, we need to impose the Neumann boundary condition for \( X^i \) and the Dirichlet boundary condition for \( X^a; \partial_\sigma X^i|_{\partial M} = 0, X^a|_{\partial M} = 0 \) where \( i = 0, 1, \ldots, p, a = p + 1, \ldots, d - 1 \). These boundary conditions result in the following constraints

\[ X_n^i - X_{-n}^i = 0, \quad P_n^i - P_{-n}^i = 0, \] (6a)
\[ X_n^a + X_{-n}^a = 0, \quad P_n^a + P_{-n}^a = 0, \] (6b)
\[ x^a = 0, \quad p^a = 0 \]
for \( n = 1, 2, \ldots \). Thus, the canonical variables are written as

\[
X^i = x^i + \sqrt{2} \sum_{n=1} Y^i_n \cos n\sigma, \quad P^i = p^i + \sqrt{2} \sum_{n=1} K^i_n \cos n\sigma,
\]

\[
X^a = \sqrt{2} \sum_{n=1} \bar{Y}^a_n \sin n\sigma, \quad P^a = \sqrt{2} \sum_{n=1} \bar{K}^a_n \sin n\sigma,
\]

where \((Y_n, K_n)\) and \((\bar{Y}_n, \bar{K}_n)\) form canonical pairs, \(Y^\mu_n = 1/\sqrt{2}(X^\mu_n + X^\mu_{-n})\), \(\bar{Y}^\mu_n = i/\sqrt{2}(X^\mu_n - X^\mu_{-n})\), \(K^\mu_n = 1/\sqrt{2}(P^\mu_n + P^\mu_{-n})\), \(\bar{K}^\mu_n = -i/\sqrt{2}(P^\mu_n - P^\mu_{-n})\). The procedure given above is equivalent to reducing a free closed string to an open string on the Dp-brane by imposing an orbifold condition: \(X^i(\sigma) = X^i(-\sigma), X^a(\sigma) = -X^a(-\sigma), P^i(\sigma) = P^i(-\sigma), P^a(\sigma) = -P^a(-\sigma)\). If these constraints are imposed, the Hamiltonian is read as

\[
H = \frac{1}{2} g_{ij} (2\pi\alpha') p^i p^j + \frac{1}{2} \sum_{n=1} g_{ij} \left\{ (2\pi\alpha') K^i_n K^j_n + \frac{n^2}{(2\pi\alpha')} Y^i_n Y^j_n \right\} + \frac{1}{2} \sum_{n=1} g_{ab} \left\{ (2\pi\alpha') \bar{K}^a_n \bar{K}^b_n + \frac{n^2}{(2\pi\alpha')} \bar{Y}^a_n \bar{Y}^b_n \right\},
\]

(7)

Now the field theoretical propagator follows from integrating over the proper-time

\[
G[X_f; X_i] = \int_0^\infty dT \langle X_f | e^{-iT\hat{H}} | X_i \rangle
\]

\[
= i \int D[\Phi] \Phi[X_f] \Phi[X_i] \exp \left( -i \int D[X] \Phi[X] \mathcal{K} \Phi[X] \right)
\]

where \(\Phi[X] = \Phi[x^i, Y^i, \bar{Y}^a]\) and \(\mathcal{K} = \hat{H}\). Hence, the Hamiltonian in the first quantized theory corresponds to the kinetic operator for string field in the second quantized theory.

III. BACKGROUND OF TACHYON CONDENSATION

The background of the tachyon condensation alters the boundary conditions for the open string on the D-brane. In order to have consistent equations of motion from the action Eq.(1) we need to impose the following boundary conditions on \(\partial M\)

\[
\left( -\frac{1}{2\pi\alpha'} g_{ij} \partial_\sigma X^j + 2u_{ij} X^j \right) \bigg|_{\sigma = \pi} = 0,
\]

(9a)

\[
\left( \frac{1}{2\pi\alpha'} g_{ij} \partial_\sigma X^j + 2u_{ij} X^j \right) \bigg|_{\sigma = 0} = 0.
\]

(9b)

If we rewrite these boundary conditions in terms of normal modes, we get
\[ \sum_n nX_n^i + i(2\pi\alpha')2(\text{g}^{-1}u)^i_j \sum_n X^j_n = 0, \quad (10a) \]
\[ \sum_n nX_n^i(-1)^n - i(2\pi\alpha')2(\text{g}^{-1}u)^i_j \sum_n X^j_n(-1)^n = 0. \quad (10b) \]

In the framework of the canonical quantization we treat them as primary constraints. Let us denote the first constraint Eq.(10a) as a primary constraint \( \Phi^i_0 \)

\[ \Phi^i_0 = \sum_n \left( nI + i(2\pi\alpha')2(\text{g}^{-1}u)^i_j \right) X^j_n = 0. \quad (11) \]

Then the commutator of the primary constraint with the Hamiltonian generates a secondary constraint \( \Psi_{i0} \), which is conjugate to the primary constraint \( \Phi^i_0 \)

\[ \Psi_{i0} = \sum_n \left( nI - 2i(2\pi\alpha')ug^{-1} \right) P_{jn} = 0. \quad (12) \]

The Dirac procedure requires further \( \{ H, \Psi_{i0} \} = 0 \) and it generates yet another constraint \( \Phi^i_1 \). We may continue this procedure until it does not generates additional new constraints.

By repetition we obtain a complete set of constraints

\[ \Phi^i_m = \sum_n \left( n^{2m+1}I + 2i(2\pi\alpha')n^{2m}g^{-1}u \right)^i_j X^j_n = 0, \quad (13a) \]
\[ \Psi_{im} = \sum_n \left( n^{2m+1}I - 2i(2\pi\alpha')n^{2m}ug^{-1} \right)^i_j P_{jn} = 0, \quad (13b) \]

where \( m = 0, 1, 2, \ldots \). All these constraints belong to the second class. We may apply the same procedure to the primary constraint Eq.(10b), but we only get a set of constraints equivalent to the set we already have. Thus, they are redundant. It is quite useful to rearrange these set of constraints. From the constraints Eq.(13a) it follows that

\[ \sum_{m=0}^{\infty} \Phi^i_m (i\sigma)^{2m} (2m)! = \sum_n \left( nI + 2i(2\pi\alpha')g^{-1}u \right)^i_j \cos n\sigma X^j_n = 0. \]

If we make use of the following simple algebra, \( \int_0^{2\pi} d\sigma \cos n\sigma \cos m\sigma = \delta(n - m) + \delta(n + m) \), we find that the set of constraints \( \{ \Phi^i_m = 0, \ m = 0, 1, 2, \ldots \} \) is equivalent to

\[ \left\{ x^i = 0, \ Y_m^i = \frac{2}{m} (2\pi\alpha') (\text{g}^{-1}u)^i_j Y_m^j, \ m = 1, 2, \ldots \right\}. \quad (14) \]

By a similar algebra, we conclude that the set of the constraints \( \{ \vec{K}_{im} = 0, \ m = 0, 1, 2, \ldots \} \)

is equivalent to the following set of constraints
\[
\begin{aligned}
\{ p^i = 0, \ K_{im} = \frac{2}{m} (2\pi \alpha') (ug^{-1})^i K_{jm}, \ m = 1, 2, \ldots \}\). \\
\end{aligned}
\] (15)

If the tachyon condensation does not occur, \( u = 0 \), the constraints reduce to \( \{ \bar{Y}_m^i = \bar{K}_{im} = 0, \ m = 1, 2, \ldots \} \), i.e., the open string is attached to a flat \( Dp \)-brane. As one of the parameters of the tachyon profile, \( u_{pp} \) is turned on and reaches the infrared fixed point, \( u_{pp} \rightarrow \infty \), the constraints for the canonical variables in the direction of \( p \) turn into the Dirichlet constraints, \( \{ Y_m^p = K_{pm} = 0, \ m = 1, 2, \ldots \} \). Therefore, we find that the open string is now attached to a \( D(p - 1) \)-brane.

If we exploit the explicit solution of the constraints, we easily see how the Hamiltonian is deformed as the condensation develops. Let us suppose that we turn on some of the tachyon profile parameters. Then the part of the Hamiltonian, which governs the dynamics of the canonical variables in the directions where the profile parameters are turned on, may be written as

\[
H = \frac{(2\pi \alpha')}{2} \sum_{n=1}^\infty \left( \bar{K}_n g^{-1} \bar{K}_n + \frac{n}{2} \frac{1}{(2\pi \alpha')^2} \bar{K}_n u^{-1} g u^{-1} \bar{K}_n \right) \\
+ \frac{1}{2 (2\pi \alpha')} \sum_{n=1}^\infty n^2 \left( \bar{Y}_n g \bar{Y}_n + \frac{n}{2} \frac{1}{(2\pi \alpha')^2} \bar{Y}_n g u^{-1} g u^{-1} \bar{Y}_n \right)
\] (16)

Thus, as \( u \rightarrow \infty \), it becomes the kinetic term for the open string variables along the Dirichlet directions

\[
H = \frac{(2\pi \alpha')}{2} \sum_{n=1}^\infty \bar{K}_n g^{-1} \bar{K}_n + \frac{1}{2 (2\pi \alpha')} \sum_{n=1}^\infty n^2 \bar{Y}_n g \bar{Y}_n.
\] (17)

IV. OPEN STRING FIELD THEORY

As the parameter of the tachyon profile is turned on, the string field and the Hamiltonian, equivalently the kinetic operator in string field theory are deformed as we expect. Now let us examine what effect the tachyon condensation background makes on the string field action. Evaluating the Polyakov path-integral over a strip we obtain the kinetic part of the string field action
\[ S = T_p \int D[X] \frac{1}{2} \Phi[X] \mathcal{K} \Phi[X] \]  

(18)

where \( T_p \) is the tension of the \( Dp \)-brane. Let us suppose that we turn on only one of the tachyon profile parameters \( u_{pp} = u \). Then, taking the constraints Eqs.(14,15) into account, we may write the measure \( D[X] \) as

\[
D[X] = D[X^p] \prod_{i=0,\ldots,p-1} D[Y^i] \prod_{a=p+1,\ldots,d-1} D[\bar{Y}^a], \\
D[X^p] = dx^p \sqrt{g} \prod_{n=1} dY^p_n d\bar{Y}^p_n \delta \left( \bar{Y}^p_n - \frac{2}{n} (2\pi\alpha') g^{-1} u Y^p_n \right)
\]

(19)

where \( g = g_{pp} \) and the metric \( g_{ij} \) is diagonal. If the tachyon condensation does not occur, \( \int D[X^p] \to \int D[Y^p] \). As the system reaches the infrared fixed point of the condensation, where \( u \to \infty \), the measure for the canonical variables in the \( p \)-th direction becomes

\[
\int D[X^p] \to \int dx^p \sqrt{g} \prod_{n=1} d\bar{Y}^p_n \left( \frac{n}{2\pi\alpha'} \right) \left( \frac{g}{2u} \right) \\
= 2\pi \sqrt{\alpha'} \sqrt{\frac{2u}{g}} \int dx^p \sqrt{g} \prod_{n=1} d\bar{Y}^p_n
\]

(20)

where we make use of the zeta function regularization.

As the tachyon condensation is turned on the string becomes inactive in the corresponding direction. Hence, it is appropriate to integrate out \( x^p \). In order to find the dependence of the string field \( \Phi \) on \( x^p \) we should be careful in defining the string propagator Eq.(8). Since the tachyon background term also contributes to the path-integral through the space-like boundary, the string propagator may be written as

\[
G[X_f; X_i] = \int_0^\infty dT \langle X_f | e^{-iT\hat{H}} | X_i \rangle e^{-\pi u x^2_p(T) - \pi u x^2_p(0)}.
\]

(21)

This expression is consistent with the analysis of the disk diagram in the boundary state formulation [6], which is related to the open string field theory by the open-closed string duality. Thanks to the constraints the propagator depends only on the zero mode \( x \) through the boundary action on the space-like boundary \( e^{-\pi u x^2_p(T) - \pi u x^2_p(0)} \). It implies that the string field \( \Phi[X] \) can be factorized as
\[ \Phi [X] = e^{-\pi u x^2} \Phi [Y, \bar{Y}] \]  

(22)

in the infrared fixed limit. Hence, the string field action becomes in the infrared fixed limit

\[
S = 2\pi \sqrt{\alpha'} T_p \sqrt{2u} \int dx e^{-2\pi u x^2} \int D[Y, \bar{Y}] \Phi [Y, \bar{Y}] \mathcal{K} \Phi [Y, \bar{Y}]
\]

\[
= 2\pi \sqrt{\alpha'} T_p \int D[Y, \bar{Y}] \Phi [Y, \bar{Y}] \mathcal{K} \Phi [Y, \bar{Y}]
\]  

(23)

where \( D[Y, \bar{Y}] = \prod_{i=0,\ldots,p-1} D[Y^i] \prod_{a=p,\ldots,d-1} D[\bar{Y}^a] \). Therefore, we find that the string field action for the open string on a \( Dp \)-brane turns into that for the open string on a \( D(p-1) \)-brane as the tachyon condensation develops. We also confirm the well-known relationship between the D-brane tensions from Eq.(23) \( T_{p-1} = 2\pi \sqrt{\alpha'} T_p \). Defining the string propagator we may construct the interacting open string field theory by gluing strings together. After the tachyon condensation occurs, the strings may be glued as usual. Depending how the strings are glued, we get the Witten’s cubic open string \[3\] or the covariant string field theory \[12\].

**V. CONCLUSIONS**

We conclude this paper with a few remarks. As the tachyon condensation develops, the \( Dp \)-brane turns into a lower dimensional D-brane. It has been well depicted in the boundary state formulation. Since the open string field theory and the boundary state formulation are related by the open-closed duality, it is reasonable to expect that the descendent transmutation of the D-branes may well be described in the framework of the open string field theory. We find that the tachyon condensation background enters into the open string field theory through the constraints to be imposed on the string variables. As the tachyon profile parameter varies, the string field on the \( Dp \)-brane transmutes into that on a lower dimensional D-brane. In this transmutation process it is also pointed out that the measure plays an important role in determining the tension of the lower dimensional D-brane.

The effect of the tachyon condensation on the open string may be seen more clearly as we evaluate the distance between two ends of the open string on the D-brane, which is given
\begin{equation}
|X(0) - X(\pi)|^2 = \sum_{n,m=1} 2(2n-1)(2m-1) \frac{(2\pi \alpha')^2}{(2\pi \alpha')^2} \bar{Y}_n^i (g_{i1}^{-1} g_{i1}^{-1} g_{i1})_{ij} \bar{Y}_m^j.
\end{equation}

Since it is order of $1/u^2$, it vanishes in the infrared fixed limit. If the tachyon condensation takes place in every direction on the world-surface of the D-brane, the two ends of the open string approaches to each other. Eventually in the infrared fixed point limit they coincide and the open string turns into a closed string.

In the present work we discuss the canonical quantization of the open string in the background of the tachyon condensation. Although some important aspects of the tachyon condensation can be understood directly in the open string field theory, there remains much room for improvement to explore the full dynamical aspects of the tachyon condensation, including the quantum corrections [13].

ACKNOWLEDGEMENT

This work was supported by grant No. 2000-2-11100-002-5 from the Basic Research Program of the Korea Science & Engineering Foundation. Part of this work was done during the author’s visit to APCTP (Korea) and KIAS (Korea).
REFERENCES

[1] A. Sen, JHEP 9808 (1998) 012, [hep-th/9805170], Tachyon condensation on the brane antibrane system ; Int. Jour. Mod. Phys. A14 (1999) 4061, [hep-th/9902105], Decent relations among bosonic D-branes; APCTP Winter school lecture, [hep-th/9904207], Non-BPS states and branes in string theory ;JHEP 9912 (1999) 027, [hep-th/9911110], Universality of the tachyon potential.

[2] V. A. Kostelecky and S. Samuel, Phys. Lett. B207 (1988) 169, The static tachyon potential in the open bosonic string theory ; Nucl. Phys. B336 (1990) 263, On a non-perturbative vacuum for the open string ; A. Sen and B. Zwiebach, JHEP 0003 (2000) 002, [hep-th/9912249], Tachyon condensation in string field theory ; N. Moeller and W. Taylor, Nucl. Phys. B583 (2000) 105, [hep-th/0002237], Level truncation and the tachyon in open bosonic string field theory.

[3] E. Witten, Phys. Rev. D46 (1992) 5467, [hep-th/9208027], On background independent open string field theory ; Phys. Rev. D47 (1993) 3405, [hep-th/9210066], Some computations in background of independent off-shell string theory ; S. L. Shatashvili, Phys. Lett. B311 (1993) 83, [hep-th/9303143], Comment on the background independent open string theory ; [hep-th/9311177], On the problems with background independence in string theory.

[4] A. A. Gerasimov and S. L. Shatashvili, [hep-th/0009103] On exact tachyon potential in open string field theory ; D. Kutasov, M. Mariño and G. Moore, [hep-th/0009148] Some exact results on tachyon condensation in string field theory ; P. Kraus and F. Larsen, [hep-th/0012198] Boundary string field theory of the $D\bar{D}$ system ; T. Takayanagi, S. Terashima and T. Uesugi, [hep-th/0012210] Brane-antibrane action from boundary string field theory.

[5] E. Witten, Nucl. Phys. B268 (1986) 253, Noncommutative geometry and string field theory.
[6] T. Lee, [hep-th/0105115], Tachyon Condensation, Boundary State and Noncommutative Solitons.

[7] C. G. Callan, C. Lovelace, C. R. Nappi and S. A. Yost, Nucl. Phys. B308 (1988) 221, Loop corrections to superstring equations of motion.

[8] E. T. Akhemedov, M. Laidlaw and G. W. Semenoff, [hep-th/0106033], On a modification of the boundary state formalism in off-shell string theory; A. Fujii and H. Itoyama, [hep-th/0105247], Some computation on $g$ function and disk partition function and boundary string field theory.

[9] T. Lee, Phys. Rev. D62 (2000) 024022, [hep-th/9911140], Canonical quantization of open string and noncommutative geometry; Phys. Lett. B478 (2000) 313, [hep-th/9912038], Noncommutative Dirac-Born-Infeld action for D-brane; Phys. Lett. B483 (2000) 277, [hep-th/0004159], Open superstring and noncommutative geometry.

[10] Note that in the boundary state formulation we take $S_T = \int d\sigma T(X)$. The boundary state formulation is related to the canonical formulation of the open string theory under discussion by the double Wick rotation.

[11] T. Lee, Ann. Phys. 183 (1988) 191, Bosonic string theory in covariant gauge.

[12] H. Hata, K. Itoh, T. Kugo, H. Kunitomo and K. Ogawa, Nucl. Phys. B283 (1987) 433, The gauge covariant action of the interacting string field.

[13] T. Suyama, [hep-th/0102192], Tachyon condensation and spectrum of strings on D-branes; K. S. Viswanathan and Y. Yang, [hep-th/0104099], Tachyon condensation and background independent superstring field theory; M. Alishahiha, [hep-th/0104164], One-loop correction of the tachyon action in boundary superstring field theory; K. Bardakci and A. Konechny, [hep-th/0105098], Tachyon condensation in boundary string field theory at one loop; B. Craps, P. Kraus, F. Larsen, JHEP 0106 (2001) 062, [hep-th/0105227], Loop Corrected Tachyon Condensation.